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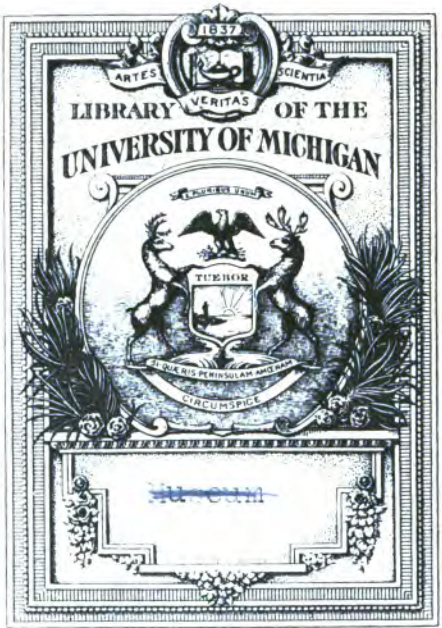

PHYSIOLOGICAL BOTANY.

GRAY'S BOTANICAL TEXT-BOOK

CONSISTS OF

VOL. I. STRUCTURAL BOTANY. By ASA GRAY.

II. PHYSIOLOGICAL BOTANY. By GEORGE L. GOODALE.

III. INTRODUCTION TO CRYPTOGAMIC BOTANY, BOTH STRUCTURAL AND SYSTEMATIC. By WILLIAM G. FARLOW. (*In preparation.*)

IV. SKETCH OF THE NATURAL ORDERS OF PHÆNOGAMOUS PLANTS; their Special Morphology, Useful Products, &c.

GRAY'S BOTANICAL TEXT-BOOK.

(SIXTH EDITION.)

VOL. II.

PHYSIOLOGICAL BOTANY.

I.

OUTLINES OF THE HISTOLOGY OF PHÆNOGAMOUS PLANTS.

BY

GEORGE LINCOLN GOODALE, A.M., M.D.,

PROFESSOR OF BOTANY IN HARVARD UNIVERSITY.

IVISON, BLAKEMAN, TAYLOR, AND COMPANY:

NEW YORK AND CHICAGO.

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PREFACE.

THE first edition of this treatise was published in the year 1842, the fifth in 1857. Each edition has been in good part rewritten, — the present one entirely so, — and the compass of the work is now extended. More elementary works than this, such as the author's First Lessons in Botany (which contains all that is necessary to the practical study of systematic Phænogamous Botany by means of Manuals and local Floras), are best adapted to the needs of the young beginner, and of those who do not intend to study Botany comprehensively and thoroughly. The present treatise is intended to serve as a text-book for the higher and completer instruction. To secure the requisite fulness of treatment of the whole range of subjects, it has been decided to divide the work into distinct volumes, each a treatise by itself, which may be independently used, while the whole will compose a comprehensive botanical course. The volume on the Structural and Morphological Botany of Phænogamous Plants properly comes first. It should thoroughly equip a botanist for the scientific prosecution of Systematic Botany, and furnish needful preparation to those who proceed to the study of Vegetable Physiology and Anatomy, and to the wide and varied department of Cryptogamic Botany.

The preparation of the volume upon Physiological Botany (Vegetable Histology and Physiology) is assigned to the author's colleague, Professor GOODALE.

The Introduction to Cryptogamous Botany, both structural and systematic, is assigned to his colleague, Professor FARLOW.

A fourth volume, a sketch of the Natural Orders of Phænogamous Plants, and of their special Morphology, Classification, Distribution, Products, &c., will be needed to complete the series: this the present author may rather hope than expect himself to draw up.

ASA GRAY.

HERBARIUM OF HARVARD UNIVERSITY,
CAMBRIDGE.

For convenience, volume second, devoted to Physiological Botany, is divided into two parts. Part First comprises the Outlines of Vegetable Histology; Part Second, soon to appear, deals with Vegetable Physiology.

Part Second will be furnished with a complete Glossary of the terms employed in Physiological Botany, and will contain a full Index to the present volume.

CAMBRIDGE, January, 1885.

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PHYSIOLOGICAL BOTANY.

INTRODUCTION.

HISTOLOGICAL APPLIANCES.

THE instruments and other appliances used in the examination of minute vegetable structure are, with the exception of a few special ones to be considered later, the following: —

1. **Simple microscope.** For the preliminary preparation of many objects, a simple stage-microscope is indispensable. It should be furnished with only the best lenses, preferably doublets or triplets, magnifying from ten to at least twenty diameters. The glass portion of the stage should be not less than an inch and a half in diameter; supports at the sides of the stage, on which the wrists may rest during dissections, are of considerable use. If the compound microscope described below is provided also with an inverting eye-piece and with an objective of long focus, it can be made to serve for most dissections; otherwise a simple microscope should always be at hand.

2. **Compound microscope.** When reduced to its simplest terms, this consists of a stage, or flat support for the object to be examined, an adjustable tube carrying two combinations of lenses, the objective and the eye-piece, and finally some means of illuminating the object. The desiderata to be borne in mind in the selection of a compound microscope for use in Vegetable Histology, are: excellence in the optical parts, ease and steadiness in their adjustment, and simplicity of construction. Other things being equal, a microscope with a short tube and with a low stand will be most convenient, on account of the large number of cases in which reagents must be employed, their application requiring a horizontal stage.

3. **Three objectives and two eye-pieces**, from combinations of which magnifying powers of forty to eight hundred diameters can be obtained, will suffice for nearly all the histological work described in this volume. Two objectives and a single eye-piece furnishing powers of sixty to five hundred diameters are enough for all ordinary investigations of minute structure. Adequate and convenient illumination is secured by a plane and a concave mirror under the stage. If this is supplemented by an achromatic condenser, so much the better. The stage, preferably thin, should be provided with a perforated revolving disc, or other suitable system of diaphragms, by which its central aperture can be made larger or smaller.

4. The student ought, at the outset of his work, to make himself familiar with the principal effects which are produced in the appearance of the object in the field of the microscope, by changes in the amount and direction of the light thrown by the mirror. Details can sometimes be brought out clearly by oblique illumination, which are only faintly, if at all, seen in direct light.

5. In general, low magnifying powers are to be preferred to higher ones; and combinations of high objectives with low eye-pieces, securing a given magnifying power, are always better than those in which low objectives and high eye-pieces are used to obtain the same enlargement.

6. The slips of glass, or "slides," upon which microscopic objects are commonly prepared and preserved, are three inches (76 mm.) long by one inch (25 mm.) wide. This is for most cases a more convenient size than that frequently employed in Germany; namely, 48 × 28 millimeters. The glass should be free from color and from imperfections. The preparation to be examined under the microscope should be covered with a disc of thin glass before it is brought under the objective. Perfect cleanliness of slide and cover-glass is absolutely necessary in all examinations, and must be secured by the exercise of scrupulous care.[1]

7. **Dissecting instruments.** Sharp delicate needles, by which

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[1] For cleaning glass perfectly, the following preparation may be used:—

A strong solution of potassic bichromate to which about half as much concentrated sulphuric acid is cautiously added. To this mixture add an equal volume of water. The glass slips, or covers, are to be kept in this solution for a short time, and then thoroughly rinsed in pure water, after which they may be dried with cloth or wash-leather. For ordinary use alcohol of usual strength answers the purpose very well.

the parts can be separated by teasing, are often better than any cutting instruments. They are indispensable in the examination of very young flower-buds, and of great use in the isolation of tissues under the dissecting microscope.

8. Sufficiently thin sections of soft parts may be made by any keen-edged knife. A razor of good quality is generally to be preferred to the ordinary dissecting scalpel, since its wide and stiff blade can be held with greater steadiness, and its steel admits of as sharp an edge. As a rule, the razor should be dipped in water before using, as this permits the steel to pass more easily through tissues.[1] If the parts from which sections are to be made are too small to be held in the fingers, they can be firmly seized between slices of pith. It is often convenient to imbed the object in paraffin or in an alcoholic solution of soap.[2] These melt below the temperature of boiling water, but are solid at ordinary temperatures, and the latter, if properly made, is transparent. A little of the melted imbedding substance is poured into a small cone of glazed paper, and when it begins to cool, the object is placed in the middle of the mass. Upon complete cooling it is firmly held therein.

Before putting the object into paraffin it should first be saturated with alcohol, and this replaced by benzol or oil of cloves, in order to enable the paraffin to hold the specimen firmly. The paraffin may be dissolved away from the sections by application of benzol, oil of cloves, or turpentine (see also 110).

9. Thin sections are best removed from the knife by a camel's-hair pencil, and are to be placed at once in water or some other liquid. Except in certain cases, water may be used as a medium for the preliminary examination of sections.

10. **Microtome.** Any of the simpler microtomes, or section-cutters, will be convenient in much histological work, and of great use in the preparation of a series of sections from any very minute object, since this permits them all to be of exactly the same thickness.

11. **Measurements.** Microscopic objects are measured by micrometers. The eye-piece micrometer can be more rapidly used than one on the stage of the instrument; and if its value

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[1] Advantage is frequently gained by moistening the edge of the knife with dilute potassic hydrate before dipping it in water, thus removing traces of oil which may have adhered to it during sharpening. But potassic hydrate should not be used in this way if reagents are to be subsequently employed.

[2] Made by dissolving enough of any good transparent soap in hot alcohol, to form, upon cooling, a firm, clear mass.

for the different objectives and for *the length of tube* has been determined accurately, it is usually preferable.

The values of the spaces in the eye-piece micrometer are ascertained by comparison with known values of the spaces on a standard stage micrometer; for example, if one space in the eye-piece micrometer corresponds to five spaces of the stage micrometer, and the latter has a value of one thousandth of a millimeter, each space of the former equals five thousandths of a millimeter.

The unit of microscopic measurement is the "micro-millimeter,"[1] one thousandth of a millimeter. It is expressed by the Greek μ.

12. **Drawing.** An image of the object under the microscope may be cast by reflection upon paper at the side of the microscope, by means of a Camera lucida. Several forms of the Camera lucida are adapted to use with the tube of the microscope in a vertical position, and are more convenient for the majority of cases coming within the scope of the present work. Oberhäuser's, Milne Edwards's, and Abbe's are of this kind.

13. **Polarizing apparatus.** This is of great use in the examination of certain contents of cells. It consists of two Nicol prisms, one below the stage of the microscope and receiving the light which is reflected from the mirror, the other in the eye-piece. Upon turning one of the prisms, distinctive optical characters, not otherwise seen, are presented by grains of starch, etc.

14. **Media and reagents.** The fluid in which a microscopic specimen is submitted to examination is technically known as its medium. Chemical agents subsequently added for the purpose of producing changes by which the chemical character of the objects may be recognized, are termed reagents. Some of the media, however, in common use produce characteristic changes in certain cases, and might be as truly referred to the latter class as several of the reagents themselves. The substances in

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[1] For convenience of reference, the following table of comparative measurements is given: —

μ.	Inches.	μ.	Inches.	Inches.	μ.
1	.000039	6	.000236	$\frac{1}{10000}$ =	2.5399
2	.000079	7	.000276		
3	.000118	8	.000315	$\frac{1}{1000}$ =	25.3997
4	.000157	9	.000354		
5	.000197	10	.000394	$\frac{1}{100}$ =	253.9972

One meter = 39.370432 inches.

which microscopic specimens are preserved are termed mounting-media.

15. MEDIA. In all ordinary cases pure water is the best medium in which to place the object for examination. If distilled water cannot be procured, filtered rain-water or melted ice will answer perfectly. In some instances water produces an immediate change either in the cell-wall or in the contents of the cells. For instance, the superficial cells of the coats of many seeds swell up at once when they are placed in water, and lose their former shape; on the other hand, important contents in the seeds of many plants are dissolved immediately when the sections are moistened. Hence, other media must be sometimes substituted for water. Absolute alcohol (see 40) is the most useful for meeting the cases above referred to. Thus, if a section of a seed-coat be first examined in absolute alcohol, and the alcohol be gradually replaced by water as directed in 17, the changes due to water will take place slowly, and can be watched throughout. For the cases in which the cell contents are suspected of undergoing change from water, castor-oil is a useful medium. If thought best, this can be removed subsequently from the specimen by alcohol or ether, and the latter in turn may be made to give place to water, and the changes can be followed with certainty.

16. Glycerin (see 60), either concentrated or somewhat diluted with water, is a highly useful medium, imparting a good degree of transparency to most specimens. It withdraws a part of the water of the cell-sap, and in the case of thin-walled cells this is followed by some change of form. The remarkable effects produced upon some of the contents of cells by the action of glycerin and similar agents will be referred to under Plasmolysis.

17. One medium may be replaced by another by the careful use of bibulous paper. Good filtering paper is the best for this purpose. If a little of the liquid which it is desired to place under the cover-glass be put at the edge of the cover, and the opposite edge be then touched lightly with the paper, the liquid will be at once drawn through. By successive applications of the same liquid, the specimen can be thoroughly washed without removal of the cover-glass.

18. REAGENTS. Four reagents are in very common use in nearly all histological examinations; namely, caustic potash, a solution of iodine, an acid, and a staining agent. Even in ordinary cases, however, it is desirable to have a somewhat wider choice than this, and therefore the following brief hints are

given as to the preparation and employment of some of the most useful reagents. More detailed directions must be sought in special treatises upon micro-chemistry.[1] The list and the general rules here given will serve for most investigations.

19. It is best to try first a very small amount of the reagent, and carefully note its effect before adding more. If it is necessary to increase the amount, draw a little through by means of bibulous paper, as previously directed. Many reagents are slow in producing their effects. Hence some time must be allowed to elapse before one reagent is replaced by another, and it is well in some cases to apply slight heat to accelerate or increase the action; but this must be very cautiously done.

20. If one reagent is to be followed by another, attention must be given to the effects which the reagents have upon each other, or upon the medium, as well as upon the specimen. For instance, small dark crystals of iodine separate from an alcoholic solution when this is brought into contact with water. Removal of the cover-glass is advised in all cases where one reagent is to be washed out before the application of a second, or where one is to be immediately followed by another, provided the specimen is not so delicate as to be disturbed by it. Some parts of the specimen are apt to escape action, if the washing or the introduction of several reagents in these operations is conducted without lifting the cover; but by the exercise of great care both these operations may be carried on successfully by the use of bibulous paper without removing the cover-glass.

21. Owing to their importance, potash and iodine are described first. The other reagents are given in alphabetical order, for convenience of reference.

22. *Potash*, *Potassic hydrate*, *Caustic potassa*, are names interchangeably given to white solid potassa and to its solutions. This substance absorbs carbonic acid so eagerly from the air, that it must be kept in glass-stoppered bottles. To prevent the stoppers from becoming fastened by the action of the alkali on the glass, it is well to smear them with vaseline or paraffin.

23. Solutions of two strengths are used. I. Concentrated. Solid potassa is dissolved in the smallest amount of water (not far from half its own weight) by which it will become liquid. This dense syrupy liquid is too strong for ordinary use. II. A common solution made with one part of solid potassa in three,

[1] Consult the following: Botanical Micro-Chemistry, by Poulsen, translated by Trelease (Cassino, Boston), 1884. Hilfsbuch by Behrens (Schwetschke, Braunschweig), 1884.

five, or ten parts of water, depending upon the particular case in which it is to be used.

24. For use as a macerating agent in separating cells, a strong solution is preferable, and is more efficient when it is slightly warmed. For dissolving or rendering transparent most of the contents of cells, more dilute solutions are better. Owing to the prompt effect produced on the cell-wall, and upon the contents of cells, especially of young ones, a moderately strong solution of potassa is the most useful clearing agent that we have. After a mass of tissue, for instance an embryo, has been acted on by a solution of potassa until it has become translucent, it is to be cautiously subjected to the action of an acid, preferably acetic or hydrochloric, and then washed. A second treatment, or even a third, may be necessary to make the object sufficiently clear. Sometimes, however, the potassa renders the tissues too nearly transparent, in which case they may be slightly clouded by a little alum-water. This process of clearing tissues was first used by Hanstein in the examination of the tissues at points of growth, and it is of very wide applicability.

25. Some structures are darkened at first by the use of potassa, but cautious treatment afterwards with a dilute acid and a second application of potassa will generally produce a good degree of transparency.

26. Potassa is a solvent for many of the substances which incrust the cell-wall, but in most cases the solutions must be used warm; in a few instances heated even to boiling. The cell-wall, washed after such treatment, will give the cellulose reactions (see 145). Suberin can thus be removed from the cell-walls of cork, forming with the potassa yellowish drops.

27. As the aqueous solution of potassa causes considerable swelling of the cell-wall, it is desirable to have also at hand an alcoholic solution. This is best made by mixing 95 per cent alcohol with a strong aqueous solution of potassa until a cloudiness appears. The mixture is then to be shaken frequently, and, after a day or so, the clear liquid above is to be carefully poured off. This solution may be diluted with alcohol if necessary.[1]

28. Solutions of caustic soda can replace potassa in most of the foregoing reactions. The special cases in which these alkalies are employed for the identification of certain contents of cells will be described later.

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[1] Russow's Potash-alcohol.

29. *Iodine.* This element is only very slightly soluble in pure water. Upon exposure to strong light, however, a somewhat larger amount of iodine passes into solution after a while, owing probably to formation of hydriodic acid. If it is necessary to examine the effect of iodine alone, as in certain parts of Lichens, a fresh solution should be used. In fact, it is recommended that in such cases a minute fragment of solid iodine be placed in pure water under the cover-glass at the moment of examination.

30. But for all ordinary examinations, a solution of iodine in water which contains iodide of potassium is used. The proportions employed vary widely. A convenient strength is obtained by dissolving one gram of iodine and five grams of potassic iodide in enough water to make one hundred cubic centimeters. Even this solution is too strong for some purposes. In a few cases a different solution is advised, made by dissolving five centigrams of iodine and twenty centigrams of potassic iodide in fifteen grams of water.[1] But, in general, dilute solutions are preferable.

31. A solution of iodine and iodide of potassium in glycerin is employed by some. An alcoholic solution is sometimes useful.

32. Iodine is a characteristic test for starch, to which it imparts a blue color, depending for its depth chiefly upon the strength of the solution. Iodine in absolute alcohol gives with dry starch a brownish color; if the alcohol is not absolute, that is, anhydrous, a blue color is given as with ordinary aqueous solutions.

33. In most cases cellulose is colored pale yellow to deep brown by iodine. If the specimen is acted on by concentrated sulphuric acid, either just before or just after the application of the iodine, a blue color appears. This reaction for cellulose is disguised by various incrusting matters, which can be removed by strong acids or alkalies; after their removal the washed specimen will give the characteristic cellulose reaction (see also 143).

34. Iodine and a metallic iodide in a strong solution of chloride of zinc form a very useful reagent for cellulose, to which a blue color is given. The reagent is easily made by dissolving pure zinc in concentrated hydrochloric acid until there is no further action of the acid. The solution, with a little metallic

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[1] Poulsen.

zinc still undissolved, is to be evaporated to a syrupy consistence, saturated with potassic iodide, and lastly enough pure iodine added to render the whole a deep red or brown. Cell-walls that have incrusting matters, for instance, cork-cells and most wood-cells, are turned yellow by this reagent. It is known as Schulze's reagent. Behrens advises the preparation of modifications of this important reagent, all depending on the relative amount of iodine and the degree of dilution. A little practice in their use will suggest the cases to which each is specially applicable. Solutions of iodine color protoplasm, and other albuminoid bodies, yellow to deep brown.

35. Owing to the tendency of iodine solutions to form hydriodic acid, it is recommended by many authors that they be kept out of the light; but this precaution is not necessary unless the investigation calls for pure iodine alone; in such a case it is better to use only freshly prepared solutions.

The following reagents are arranged in alphabetical order.

36. *Acetic acid.* Glacial acetic acid diluted by two or four parts of water, or the ordinary concentrated acid of the shops, is used (1) to neutralize the alkali in Hanstein's method (see 24); (2) to discriminate between oxalates and carbonates, the latter dissolving with effervescence in it, the former remaining unchanged in it, but dissolving quietly in hydrochloric acid; (3) in the study of the nucleus.

37. *Alcohol.* Common strong alcohol, or the so-called "95 per cent," is widely employed for the preservation of microscopic material. In it soft tissues become hardened. This is a great advantage in the case of specimens which are too yielding to be cleanly cut when fresh. If it is desirable to again soften tissues which have been hardened by the action of alcohol, it is merely necessary to soak them for a short time in water, when they will assume nearly the consistence they had when fresh. This reagent produces certain marked changes in the contents of vegetable cells: the protoplasmic matters become more or less shrunken, many oils and fats are dissolved, and certain substances in solution in the cell-sap are separated out (see 183).

38. The air which occurs in intercellular spaces and in all dry specimens is generally removed with ease by the action of alcohol, especially if a little heat is applied.

39. Alcohol is of use also in the preparation of some of the staining agents.

40. Absolute alcohol contains only the merest trace of water. Hence it must be used instead of ordinary alcohol whenever the

specimen is affected by water, as is the case with mucilaginous tissues, crystalloids, etc. As a reagent for use under the cover-glass it is more satisfactory than common alcohol, but in keeping it the greatest care must be exercised to exclude moisture.

41. *Alum.* Either potash- or ammonia-alum may be used to diminish the transparency of cells which have been acted on by potassa (see 24). Alum is a mordant in some of the processes for staining (see 98).

42. *Ammonia.* Aqueous ammonia may replace the fixed alkalies, potassa and soda, but possesses no advantage over them except in its somewhat slower and less violent action. For its use in the examination of albuminoids, see 125. Its principal use in microscopy is in the preparation of certain staining agents (see 77) and cuprammonia.

43. *Anilin chloride.* Dissolved in alcohol, this reagent imparts a pale yellow color to lignified cell-walls. Upon addition of hydrochloric acid, the color is much deepened. This is Höhnel's test for lignin.

44. *Anilin sulphate.* This substance in aqueous or alcoholic solution gives to lignified cell-walls a pale yellow color, which is much deeper when the reagent is followed by sulphuric acid, — Wiesner's test for lignin.

45. *Argentic nitrate*, or nitrate of silver, in extremely dilute alkaline solution freshly made, has been recommended for discriminating between living and dead protoplasm, the former turning dark, the latter remaining unchanged (see details in Part II.).

46. *Asparagin.* A concentrated solution of asparagin is suggested by Borodin for the recognition of asparagin itself when its crystals have been formed in tissues blanched by darkness.

47. *Auric chloride*, long used for staining preparations in animal histology, has been somewhat employed for coloring the cells of certain lower plants, and in the same manner as argentic nitrate, for detecting the condition of protoplasm.

48. *Benzol* is a powerful solvent for various vegetable fats and resins. It is also used for the preparation of benzol-balsam (see 112), and in dissolving paraffin (see 8).

49. *Calcic chloride.* Treub employs this for clearing tissues. The fresh section, after having been moistened by a little water, is covered with dry powdered chloride, warmed until it is about dry, and afterwards placed in a little water.

From this it is to be transferred to glycerin, where it soon becomes clear.[1]

50. *Calcic hypochlorite* in aqueous solution bleaches many tissues without the use of an acid, but, in general, specimens which have been subjected to its action are more thoroughly decolorized if they are subsequently placed in dilute hydrochloric acid, washed in pure water, and finally transferred to glycerin. Preparations which have been bleached by this method are easily colored by some of the staining agents described on page 15. Sodic hypochlorite may replace it in all cases.

51. *Carbon disulphide* is used as a solvent for fats.

52. *Carbolic acid*, or phenol, dissolved in the least quantity of concentrated hydrochloric acid which will take it up, gives a green color with lignified cells. It is better to add to a few drops of the strongest hydrochloric acid a small quantity of crystallized phenol, warm the mixture slightly, and upon its cooling add enough acid to remove any cloudiness.

53. *Chloral hydrate* in aqueous solution is recommended by Arthur Meyer[2] as a clearing agent. Two parts of water are added to five parts of chloral, and used somewhat above the temperature of 15° C.

54. *Chromic acid.* The pure acid, in strong solution, acts promptly on cell-walls, dissolving all except those which are silicified and those which are cutinized. Even the latter yield to prolonged action. If the solution is more dilute, the action goes on only so far as to cause swelling of the cell-wall, bringing out, in special cases, a very distinct stratification. Solutions which are so dilute as to be merely pale yellow cause hardening of soft tissues, and this acid therefore forms an excellent adjuvant to alcohol for this purpose (see Part II.).

55. *Cuprammonia.* To a solution of cupric sulphate add enough soda (or potassa) to produce a precipitate. After removal of the excess of liquid by filtration, place the precipitate in a flask, wash once with water which has been freed from air by boiling, and then dissolve the mass in the least quantity of concentrated ammonia which will take it up. The freshly prepared solution should act promptly on delicate fibres of cellulose, cotton for example, causing them to swell and apparently pass into solution. Lignified and cutinized cell-walls are not acted

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[1] Flahault: Accroissement terminal de la racine. Ann. des Sc. nat., 1878. vi. p. 24.

[2] Das Chlorophyllkorn, Leipzig, 1883.

upon until the foreign matter has been removed by the agents previously spoken of (see 26).

This reagent, known as Schweizer's,[1] possesses its chief interest from the fact that it is the only liquid known in which cellulose appears to dissolve without essential change of composition. It has a limited application in the discrimination of fibres used in the arts.

56. *Cupric acetate* in aqueous solution is used as a preparatory liquid for the examination of resins. The part to be examined is kept in a concentrated solution for some days, and sections are then made from it. If certain resins are present, they will appear of a green color. The above is Franchimont's test based on a reaction discovered by Unverdorben.[2]

57. *Cupric sulphate* in saturated aqueous solution is used for the detection of certain carbohydrates (see 184) and albuminoidal matters (see 124). Commercial blue vitriol, recrystallized two or three times, will answer for all ordinary cases.

58. *Ether* is used as a solvent for fats, etc.

59. *Ferric chloride* in aqueous solution was formerly recommended as a test for the tannins;[3] the tannin of oak-bark becoming bluish-black; that in the leaves of the sumach, greenish-black. But the distinctions are not constant. Ferric acetate and sulphate are now more generally used than the chloride as a test, and are better.

60. *Glycerin.* Only the purest glycerin should ever be employed in microscopic examinations. The following are among the most important of its many applications: 1. In clearing specimens. It is used not only as an adjuvant in the Hanstein and other methods of clearing, but, in many cases, it serves well without any other reagent. 2. To cause withdrawal of water from fresh cells, the degree of effect depending on the strength of the glycerin. 3. In the examination of protein granules (see 175). 4. As a test for inulin; this substance separates sooner or later in the form of sphærocrystals. 5. As a solvent for iodine (see 31).

61. *Hydrochloric acid.* Pure concentrated acid is one of the most satisfactory agents for the maceration of woody tissues. When dilute, it serves for the discrimination between carbonates and oxalates, the former dissolving with effervescence, the latter

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[1] Schweizer: Vierteljahrsschrift natur. Ges., Zurich, 1857.
[2] Behrens: Hilfsbuch, p. 377.
[3] Watts's edition of Fownes's Chem., p. 672.

without. It must be remembered that acetic acid dissolves carbonates, but not oxalates (see 36).

This acid has been used by Pringsheim[1] in the study of chlorophyll grains; fresh sections of tissues containing chlorophyll being exposed to the action of the acid for some hours. From the grains, minute spheres of a brownish color become nearly detached, and these afterwards appear as clusters of acicular crystals (see Part II.). Hydrochloric acid is also of use in the examination of some protein matters (see 124).

62. *Indol* (Niggl's test[2] for lignin) is used in an aqueous solution. The specimen, subjected to the action of the solution for a few minutes, is transferred to sulphuric acid of specific gravity 1.2 (made by adding one part of concentrated acid to four parts of water). Lignified structures become red.

63. *Mercuric chloride*, or corrosive sublimate, dissolved in fifty parts of absolute alcohol renders protein grains insoluble in water. Pfeffer[3] recommends that the specimen should remain in this reagent at least twelve hours. Dippel[4] uses a dilute aqueous solution (1 in 500) to render visible the currents in the most delicate threads of protoplasm (and for the demonstration of the nucleus without affecting the other contents of the cell).

64. *Millon's reagent*, commonly called acid nitrate of mercury, is best prepared, according to its discoverer, by pouring upon pure mercury its own weight of concentrated nitric acid. For a short time the action is violent; when it subsides a little, gently warm the liquid until the metal is completely dissolved. The solution is immediately diluted by twice its volume of pure water. After a few hours the liquid is to be decanted from the crystalline mass which has formed, and it is then ready for use.[5]

This reagent is more efficient when freshly made.

Albuminoid substances are colored red by this reagent even in the cold, but much more readily upon the application of heat. According to Millon, the reaction is due to the presence in the liquid of both mercuric nitrate and nitrite.

This reagent has been employed for the demonstration of the stratification and spiral striation of certain cell-walls.

65. *Nitric acid* gives to protein matters a yellow color, which is intensified upon the subsequent use of ammonia. The

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1 Pringsheim's Jahrbücher, Bd. xii. p. 294, *et seq.*
2 Flora, 1881, p. 545, *et seq.*
3 Pringsheim's Jahrbücher, viii. p. 441.
4 Dippel: Das Mikroskop, i. p. 281.
5 Quoted from Behrens: Hilfsb. p. 247.

same treatment, especially if the slide is slightly warmed, colors the so-called intercellular substance yellow. The acid is also used as a test for suberin (see 158).

66. *Osmic acid* (perosmic acid) is very volatile, and therefore is best preserved in sealed glass tubes until wanted for use, when the tube can be broken under water. Even from the aqueous solution the irritating acid escapes in small amount, rendering it a disagreeable reagent to work with. The solutions are usually of one per cent strength.

Oils are colored brown by the reduction of the acid to metallic osmium on the surface of the drops. Living protoplasm is killed at once by even dilute solutions of this acid, and there is usually more or less discoloration of the different parts. Hence it is a useful agent for arresting the processes of cell-division and growth at any desired stage. Advantage is sometimes gained, according to Poulsen,[1] by the combination with it of chromic acid.

67. *Phenol* (see carbolic acid, 52).

68. *Phloroglucin*, used by Wiesner as a test for lignin.[2] The specimen is first acted on by hydrochloric acid, and then moistened by a solution of phloroglucin in water or alcohol. If the cell-walls are lignified, they will at once assume a red color. Höhnel[3] suggests the employment of a strong decoction of cherry wood instead of the phloroglucin. Used in the same way, it imparts a violet color to lignified cells. This test is hardly so satisfactory as the other.

69. *Potassic bichromate* in aqueous solution is used to harden tissues, and is about as good as chromic acid. It has been also employed by Sanio[4] for the detection of tannin.

70. *Potassic chlorate*, used with nitric acid, is the most convenient macerating agent. If a few small crystals of this salt are added to a little concentrated nitric acid in a test-tube containing a fragment of wood, and the liquid is carefully warmed, violent action begins somewhat below the point of boiling, and the wood is speedily disintegrated. By selecting acid of the right strength, and by careful regulation of the heat applied, the action of the liquid can be kept well under control, so that almost any degree of action can be obtained. It is not safe to use this reagent in the room where delicate apparatus is kept,

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[1] Mikrochemie, p. 19.

[2] Sitzungsber. Akad. Wien, 1878, p. 60.

[3] Ib. 1877, p. 685.

[4] Bot. Zeitung, 1863, p. 17.

since the gases evolved act upon metals. This is Schulze's macerating process.

71. *Potassic nitrate*,[1] used in the examination of protoplasm (see Part II.).

72. *Rosolic acid*, or corallin, dissolved in water containing a trace of sodic carbonate, forms a purple fluid which colors vegetable mucus red. It is used also to demonstrate the structure of cribrose-tissue.[2]

73. *Schweizer's reagent* (see cuprammonia).

74. *Sodic chloride* (common salt), used in aqueous solution in the examination of protoplasm (see 120).

75. *Sugar*. Cane sugar dissolved in water to form a thick syrup is allowed to act for some time on tissues containing protoplasm: a drop of concentrated sulphuric acid is then placed on the object, when the protoplasm will take on a faint rose-red color. The reaction is uncertain.

76. *Sulphuric acid*. Pure concentrated acid is used as an adjuvant in many tests, *e. g.*, with iodine solutions in the identification of cellulose, but it is also of great use by itself in breaking down cellulose. By it, a cellulose wall can be destroyed without destruction of the protoplasm within (see 141).

77. **Staining agents.** A few of the chemicals in the foregoing list impart to certain tissues, and certain contents of cells, colors which have a good degree of permanence when the specimens are preserved in a suitable medium. But the colors produced by most reagents are fugitive, and serve only a temporary purpose. When, therefore, it is desirable to stain or tinge a given part of a specimen permanently, recourse must be had to dyes which do not readily fade.

78. Some of these have been long in use in Vegetable Histology for the purpose of preparing attractive specimens for the demonstration of tissues, but it is only within a recent period that they have been successfully employed in the study of cell-division. In the examination of the changes which take place in the interior of cells during division, they are indispensable: in the examination of the tissues themselves, their use is far from satisfactory. As will be specially shown later, the chemical differences between the cell-walls of certain tissues which it is desirable to distinguish from each other under the microscope are not very great, and they often behave alike as respects

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[1] Treub: Naturk. Verh. d. koningl. Akad. vol. xix., 1878, p. 9.

[2] Behrens: Hilfsbuch, p. 313.

staining agents. Hence it is impossible to lay down rules which will apply to all cases in which tissues are to be stained: the staining of the nucleus, however, can be readily secured by following the explicit directions given in the chapter on "Cell-growth."

79. Of the whole class of staining agents, it may be said that exposure to strong light diminishes the brilliancy of the coloring they produce in the specimen, and in many cases completely destroys it. In general, the staining obtained by allowing the specimen to remain for a long time in a dilute solution of a dye is more satisfactory than when a stronger dye is used with haste.

80. Carmin. Two grades are readily procurable in this country; namely, (1) "No. 40," (2) "Orient." The former is the cheaper, and will answer for all cases described in this treatise; but attention must be called to the fact that it is sometimes adulterated, and hence it may be found necessary to change the proportions given in the following formulas. A good carmin, even of the grade first mentioned, should leave only little residue when placed in strong ammonia. If more than a trace of residue is found, the amount of carmin in the formula must be proportionately increased.

81. *Ammonia-carmin.* Pure powdered carmin is rubbed up with a little water to form a thin paste, enough strong ammonia to dissolve it is cautiously added, and the whole is then filtered. The filtrate is to be evaporated slowly over a water-bath. The dried mass dissolves readily in water, forming a clear liquid which keeps well; but it is better to preserve the mass in a tightly-stoppered bottle, dissolving it only as required (Hartig's carmin).[1]

82. A modification of this carmin is made as follows: .2 to .4 gram of carmin is shaken up with 30 c.c. of water, and a few drops of ammonia added. A part of the carmin dissolves, and is to be filtered. If the filtrate smells strongly of ammonia, it is allowed to stand for half a day under a bell-jar. A drop of ammonia will re-dissolve any slight trace of carmin which may separate. This fluid is to be added to water, drop by drop, until the right color is obtained (Gerlach's ammonia-carmin).[2]

83. If, to the filtrate last mentioned, 30 grams of glycerin

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[1] Dippel: Das Mikroskop, i. p. 284.
[2] Behrens: Hilfsbuch, p. 257.

and 10 grams of strong alcohol are added, a liquid is obtained which is known as Frey's glycerin-carmin.

84. *Beale's carmin* is nearly the same. Ten grains of carmin are placed in a test-tube, and half a drachm of strong ammonia added; the mixture is shaken, and gently heated over a spirit-lamp. The solution is to be boiled for a few seconds and then allowed to cool. In an hour two ounces of glycerin and two ounces of water are to be added, together with half an ounce of alcohol; the liquid is then filtered.[1]

85. *Thiersch's borax-carmin.*[2] 2 grams of borax are dissolved in 28 c. c. of distilled water, and .5 gram of carmin added. The solution is next mixed with 60 c. c. of absolute alcohol, and filtered.

86. *Thiersch's oxalic-acid carmin.*[3] 1 gram of carmin is dissolved in 1 c. c. of ammonia and 3 c.c. of water. Another solution is prepared by dissolving 8 grams of crystallized oxalic acid in 175 c. c. of water. The two solutions are then mixed, 16 c. c. of absolute alcohol added, and the whole filtered. This liquid is violet when ammonia is in excess; orange, if too much oxalic acid is present.

87. *Grenacher's alum-carmin.*[4] Carmin is dissolved in a solution of potash-alum or ammonia-alum until the required color is obtained. This has been modified by Tangl as follows: To a saturated solution of alum, enough carmin is added to give a deep color (1 grm. in 100 c. c. of solution), the whole boiled for ten minutes, and filtered upon cooling.

88. *Woodward's carmin.* "Pulverized carmin 7½ grains, water of ammonia 20 drops, absolute alcohol half an ounce, glycerin 1 ounce, distilled water 1 ounce. Put the pulverized carmin in a test-tube and add the ammonia. Boil slowly for a few seconds, and set aside uncorked for a day, to get rid of the excess of ammonia. Add the mixed water and glycerin, and next the alcohol, and filter."

89. *Carmin with picric acid.* This agent, known as Ranvier's picrocarmin, is made by cautiously adding to a concentrated solution of picric acid enough ammonia-carmin solution (81) to saturate it, and then evaporating to one-fifth the volume.

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1 Beale: How to Work with the Microscope, p. 125.

2 Behrens: Hilfsbuch, p. 258.

3 Behrens: Hilfsbuch, p. 257. In Dippel (Das Mikroskop), p. 285, the proportions are somewhat different.

4 Archiv. für Mikrosk. Anat., 1879, p. 465. Tangl, in Pringsh. Jahrb., Bd. xii., 1880, p. 170.

Upon cooling, a slight sediment is deposited. After filtration from this sediment the liquid is evaporated to dryness, and afterwards dissolved in water in the proportion of 1 : 100.

Another formula is: 1 gram of carmin and 4 c. c. of concentrated ammonia are mixed with 200 c. c. of water, and 5 grams of picric acid then added. After nearly complete solution the clear liquid is poured off, and exposed to the air for some weeks. The red powder left after this slow evaporation is to be dissolved when required in water in the proportion of 2 : 100, and the solution filtered through two thicknesses of filter-paper.

Cochineal, the substance from which carmin is prepared, may be used in aqueous extract, or with alum. The formula for the preparation with alum is given as follows: Rub to a fine powder one gram of cochineal with one gram of burnt alum; mix with 100 c. c. of water, and boil down to 60 c. c. When cold, filter the solution several times, and add a few drops of carbolic acid.

90. *Hæmatoxylin* (a dye obtained from logwood) is used dissolved in alcohol, or alum-water, according to circumstances.

Frey gives the formula: 1 gram of hæmatoxylin is dissolved in absolute alcohol. This solution is added, drop by drop, to a three per cent aqueous solution of alum, until it becomes deep violet in color. After exposure to the air for a few days, it is to be filtered, and is then ready for use; but a fresh filtration will be found necessary after a time. Poulsen advises that a few drops of a ten per cent solution of alum be added to an aqueous solution of hæmatoxylin (.35 gram in 10 c. c. water).

Aqueous extracts of several other dye-woods can replace hæmatoxylin in some cases, but they have no advantage over it.

91. *Picric acid* (trinitrophenic acid) in aqueous solution is valuable for staining and hardening protoplasm. It may be used alone, combined with carmin (see 89), or with nigrosin.

92. Alkanet-root (alkanna) in alcoholic solution tinges resinous globules and serves to prepare for cutting specimens which contain them. The method of use is described under "Resins."

93. *The coal-tar colors.* Under this name are comprised the anilin derivatives and a few others of a slightly different origin. The following table will indicate to some extent the changes of color which may be expected when these dyes are used with tissues which have a marked acid or alkaline reaction. But it should be observed that the names of several of the dyes are loosely applied, and that the dyes made by different manufacturers are not always of the same character or strength. All of the dyes mentioned below are soluble in water and alcohol.

Name.	Effect of dilute H.Cl.	Effect of dilute Ammonia.
	Red dyes.	
Magenta.	Color fades to brown or light purple.	Fades completely.
Safranin.	Color changes to purple, and a brown precipitate occurs.	Little change.
Red anilin.	Deep orange-brown color.	Reddish precipitate.
Acid azo-rubin.	Slight change of tint.	Little change.
Eosin.	Orange precipitate.	No marked change.
Ponceau.	No change of color	No change.
	Yellow and Orange dyes.	
Solid yellow.	Purple precipitate.	Little change.
Orange "R."	Unchanged.	Unchanged.
Gold orange.	Little change.	Color deepens to red.
	Green dyes.	
Methyl-green.	The bluish tint becomes deep green.	Fades out.
Brilliant green.	Fades somewhat.	Whitish precipitate.
Emerald green.	Fades out.	Whitish precipitate.
	Blue and Violet dyes.	
Cotton-blue "B."	Unchanged.	Fades somewhat.
Methyl-violet "BBBBBB."	Greenish precipitate.	Purple precipitate.
Nigrosin.	Little change.	Little change.

94. A solution of any of the above dyes consisting of one gram with enough water to make one hundred cubic centimeters, although too strong for most cases, is very convenient, since it can easily be diluted at will. From even very dilute solutions parts of a specimen, for instance, a cross-section of a stem, will take up some of the color with more or less change. If the staining is too deep, a part of the color can be removed by careful washing in alcohol, or in a very dilute acid or alkali (see above table for each case).

95. *Double-staining.* It is sometimes possible to color different parts of a specimen with more than one dye; for instance, staining the fibres of the bark green, and the wood of the same specimen red. The best results are obtained by the use of an alcoholic solution of one of the dyes and an aqueous solution of the other. The following method proposed by Rothrock[1] gives excellent results. The dyes are Woodward's carmin (see 88) and anilin green (or "iodine green"). The specimen (whether bleached by sodic hypochlorite or left unbleached) is first thoroughly saturated by alcohol, which hardens it, and causes contraction of the contents; it is then kept for a day in a dilute

[1] Botanical Gazette, September, 1879.

alcoholic solution of anilin green. In a row of watch-crystals the following liquids are placed: (1) water, (2) Woodward's carmin, (3, 4, 5) alcohol, (6) absolute alcohol, (7) oil of cloves. The specimen, taken from the green, is dipped for a moment in water, then for about a minute in the carmin, then successively through the alcohols, in each of which it remains ten to twenty minutes, except in the first, where it remains only long enough to have the unfixed carmin washed away. From the last alcohol it goes into oil of cloves (or benzol), where it should remain long enough to become perfectly transparent. It is then to be mounted in balsam.

96. Double-staining can also be effected by the successive use of hæmatoxylin and an anilin color. By the use of two or more anilin dyes different parts of a specimen may be colored differently; but as a rule all these effects are uncertain, and cannot be relied upon for the positive identification of tissues. In general, however, long bast fibres take characteristic colors.

97. The following combinations for double-staining are recommended by Dr. Stirling,[1] and though originally designed only for animal tissues, serve well with sections of plants: —

1. Osmic acid and picrocarmin. 2. Picric acid and picrocarmin. 3. Picrocarmin and logwood (hæmatoxylin). 4. Picrocarmin and an anilin dye. 5. Logwood and iodine green. 6. Eosin and iodine green. 7. Eosin and logwood. 8. Gold chloride and an anilin dye.

98. In the cases which require special treatment, for instance, the staining of the nucleus, the precautions laid down must be attended to in order to insure success. But in the ordinary instances where it is desirable to stain a specimen merely to bring some part into prominence for purposes of demonstration, the widest choice in dyes and their use is advised. A few mordants have been tried in order to fix the colors, but with little success. The best are tannin in solution, and aqueous solutions of any of the alums. A little practice will show which mordant is best for each case.

99. Specimens stained by nearly all of the above dyes can be mounted securely in balsam, as directed in section 110; but glycerin and glycerin-jelly mounts are apt to become faded or discolored after a time.

100. **Mounting-media.** Pollen and other dry specimens are preserved in shallow cells formed by a thin ring of asphalt-

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[1] Journ. Anat. and Phys., 1881, p. 349.

cement, varnish, or white lead, allowed to dry nearly to hardness, upon which a cover-glass fits firmly, and is retained by a second ring of the same cement. If the precaution is taken to have the cover-glass fit evenly to the first layer of cement, there is little danger that the subsequent layer, which is to hold the cover in place, will creep under it and into the cell.

101. Glycerin, pure water, calcic chloride solution, potassic acetate, and like liquids may be used as mounting-media in cells prepared in the manner just mentioned, but made of greater thickness. Care must be observed to avoid touching the upper edge of the cement ring with the liquid; and yet the cell must be completely filled, in order to exclude air.

102. If a specimen has been prepared in glycerin, and it is not considered well to disturb the cover-glass, a cement ring or square can be built up around the cover at a little distance from it, *provided* the glass slide is thoroughly cleaned at the place where the cement is to be put. After the requisite number of layers have hardened sufficiently, a ring of the same or, better, of a more quickly drying cement may be placed across from the edge of the cell to the cover-glass, to hold it in place. As this, in drying, will contract somewhat, it is a good plan to place two or three fragments of thin glass under the cover, that these may receive the pressure and prevent crushing the specimen.

103. Of the mounting-media, one of the best is glycerin and acetic acid in equal parts, boiled and filtered. It serves well for thin-walled specimens (especially in the lower plants).

104. Specimens of fresh cells or of juicy tissues which are to be mounted in glycerin are best treated in the manner recommended by Beale.[1] "The specimen is first immersed in weak glycerin, and the density of the fluid is gradually increased, either by adding from time to time a few drops of strong glycerin, until it bears the strongest, or by allowing the original weak solution to become gradually concentrated by slow evaporation. In this way, in the course of two or three days the softest and most delicate tissues may be made to swell out almost to their original volume in the densest glycerin or syrup. They become more transparent, but no chemical alteration is produced, and the addition of water will at any time cause the specimen to assume its ordinary characters."

105. It is plain that mounts in any liquid must be liable to injury from displacement of the cover-glass; but this can be

[1] How to Work with the Microscope, p. 360.

partially guarded against by fastening to the upper surface of the slide, near its two ends, square pieces of pasteboard a little thicker than the cell itself.

106. *Glycerin-jelly*, a mixture of glycerin with pure gelatin, is liquid at the temperature of boiling water, and solidifies again on cooling. Any specimen which is not injured by being slightly heated can be mounted satisfactorily in the jelly, *provided* it is first thoroughly saturated with glycerin. But this precaution is by no means necessary in all cases.

107. A drop of the melted jelly, free from air-bubbles, is placed on the slide (a fragment of the solid jelly can be melted on the slide if preferred), the specimen placed therein, and the cover-glass, previously moistened slightly on the under side with glycerin, is carefully laid on, and the preparation now allowed to cool. When the jelly is again hard, a varnish or cement ring may be placed around the edge of the cover to hold it in place. Asphalt-cement is apt to impart to the jelly a dark tinge, which may sooner or later spoil the mount, and hence the colorless varnishes are better.

108. The edge of the jelly may be lightly touched with a strong solution of a chromate, for instance, bichromate of potassium, and exposed for a while to light. This renders the jelly insoluble, and firmly sets it.

109. The following are among the best formulas for making this useful mounting-medium: —

One part of pure gelatin, three parts of water, and four of glycerin (Schacht, quoted by Dippel). Nordstedt uses the same proportions, and advises the addition of a small piece of camphor or a drop of carbolic acid, to prevent moulding.

One part of gelatin is soaked in six parts of water for two hours, seven parts of glycerin are added, and one per cent of carbolic acid is added to the whole. The mass is heated for fifteen minutes, with constant stirring, and then filtered through glass-wool. All the ingredients must be absolutely pure (Kaiser, Bot. Centrbl., 1880, p. 25).

The proportions employed in the second formula, but without the addition of the carbolic acid, give a clearer jelly; and it has not been apt to mould, especially if the cork of the bottle containing it be wrapped in a thin piece of linen, which has been dipped in dilute carbolic acid.

110. *Canada balsam.* This is used either (1) alone, or (2) in solution. In either case the specimen must be free from water, and permeated by some liquid easily miscible with the balsam.

This is easily effected by first saturating the object with alcohol (beginning preferably with dilute, and then using stronger), in order to expel all water; next placing the alcoholic specimen in oil of cloves, turpentine, or benzol, until the alcohol is in turn expelled. The specimen thus permeated is transferred to balsam which has been previously placed on the slide. Care must always be taken to have the balsam perfectly free from air-bubbles.

111. When used alone, the balsam on the slide may be heated, to drive off a part of its more volatile constituents, and the specimen can then be placed in the warm liquid. But this method is not applicable when the specimen is affected by slight heating; it is best adapted to hard tissues, like woods and fibres. Balsam which has thus been heated hardens on cooling to a good degree of firmness. This firmness is secured with balsam used without heat only after a longer lapse of time, during which the more volatile matters have escaped.

112. If pure balsam is cautiously heated in a capsule until it no longer gives off vapors, the melted mass will cool into a pale amber-colored solid. This solid dissolved in a small quantity of benzol forms a liquid of the consistence of syrup, which is useful for all mounting where heat is injurious. The specimens must be treated successively with alcohol and benzol, and they are then ready to be immersed in the benzol-balsam on the slide. An equally serviceable solution is made by dissolving the mass in chloroform. Chloroform-balsam requires the specimen to be saturated with chloroform before immersion.

113. In all the above cases two precautions will save disappointment: 1st. the slides and cover-glasses should be heated slightly, to drive off any moisture on the surfaces which are to come in contact with the mounting-medium; 2d. the covers should be held in place by means of a slight weight, or by the pressure of a spring clip, until the balsam or its solution has become tolerably firm. A little experience will show that specimens mounted in balsam may require a somewhat different management of the mirror under the stage from those which are mounted in a medium with a different refractive power. *Damar* may replace balsam when the latter, which is the better, is not to be had.

114. *Hoyer's mounting-media* are highly recommended by Strasburger.[1] The one which is preferred for anilin preparations

[1] Das botan. Practicum, 1884, p. 40.

is made by adding colorless pieces of gum-arabic to a solution of potassic acetate or ammonic acetate, until the liquid becomes of the density of thick syrup, while in that intended for carmin preparations the gum is dissolved in a five to ten per cent aqueous solution of chloral hydrate, and about ten per cent of glycerin added. Either of these media, or a plain solution of pure gum-arabic, will be found to answer admirably for all preparations of woods which are to be photographed.

115. The edges of the cover-glass are usually painted with some varnish of good quality. Those in best repute are: —

1. Asphalt-varnish, to be thinned with turpentine when too thick.
2. Maskenlack, a German preparation, thinned with alcohol.
3. Mikroskopirlack, also thinned with absolute alcohol.
4. Shell-lac in alcohol, tinged with some anilin color. If a few drops of castor-oil are added to the solution, it dries into a less brittle finish.
5. Gold-size.
6. White lead (with oil).

It is a good plan to revarnish slides whenever the varnish first shows any indication of breaking away.

A few works in regard to microscopic manipulation and micro-chemistry which may be advantageously consulted by the student are the following: —

BEALE. How to Work with the Microscope (London). This is a large octavo volume, with very minute descriptions of microscopical appliances and manipulation. Several editions have been printed.

CARPENTER. The Microscope (London). A small octavo of about 900 pp. This work deals at some length with the structure of animals and plants.

BEHRENS. Hilfsbuch zur Ausführung Mikroskopischer Untersuchungen im Botanischen Laboratorium (Braunschweig, 1883). This is specially devoted to microscopic manipulation and micro-chemistry. An English translation is promised.

POULSEN. Botanical Micro-Chemistry. Translated and enlarged by Professor Wm. Trelease (Boston, 1884). An excellent account of the chemicals used in the examination of vegetable structures, together with some directions for their employment.

STRASBURGER. Das botanische Practicum. See an account of this work on page 165.

PART I.

CHAPTER I.

THE VEGETABLE CELL IN GENERAL: ITS STUCTURE, COMPOSITION, AND PRINCIPAL CONTENTS.

116. **The unit in Vegetable Anatomy,** the fundamental component of which the fabric of plants is constructed, and from which all the diverse histological elements are derived, is the cell. Even the elements which are the least cellular in appearance, and which have names of their own (as fibres, ducts, etc.), are only transformed cells, or simple combinations of them; so that the cell is the type as well as the unit of vegetable structure, as indeed it is of animal structure also. The name *cell* is one which would not be given to it if the nomenclature were to be founded upon our present knowledge. Cells were originally taken to be only closed cavities in a vegetable mass.[1] We now

[1] The earliest recognition of cellular structure in plants appears in Robert Hooke's **Micrographia** (1665), p. 113. "Our microscope informs us that the substance of cork is altogether fill'd with air, and that that air is perfectly enclosed in little boxes or cells distinct from one another."

Nehemiah Grew, of London (The Anatomy of Plants, book i. p. 4), under date of 1671, says of the mass through which the framework of a young plant is distributed, "It is a Body very curiously organiz'd, consisting of an infinite number of extreme small bladders," etc.

Malpighi, of Bologna, in a work presented to the Royal Society in the same year, uses nearly the same language: "Exterior etenim cuticula utriculis, seu sacculis horizontali ordine locatis, ita ut annulus efformetur, componitur, etc." (Anatomes Plantarum Idea, p. 2).

As a preliminary study, a beginner should prepare and examine a few sections like the following: —

(1) From the tip of the root of a bean (which has germinated on wet sponge or paper) cut a thin section lengthwise, and carefully examine it under a power of 200–400 diameters. If the section is thin enough, the contents of the cells can be made out, and will be seen to consist of a colorless lining (*protoplasm*), in which one part (*the nucleus*) appears denser than the rest. Next, treat the section with a solution of iodine, and notice what parts are colored, — the protoplasm and nucleus are yellow and brown, but the cells on the looser part of the tip contain bluish granules (*starch*). This starch can best be shown by first dissolving out the protoplasm with dilute potash.

know them to be organs and even organisms. Histology therefore begins with the cell in its independent condition.

117. A complete and living vegetable cell consists of a cell-wall enclosing certain essential contents.

118. In their earliest state some of the lower plants exist as a mass of motile living matter, not bounded by any envelope. But in all plants of the higher grades the living matter of the cell is from the very first protected by a cell-wall.

119. That which is essential to the vital activity of a cell is an apparently half-solid substance, — protoplasm. With the properties of protoplasm as a living thing, Physiology and not Histology is immediately concerned. But it is necessary throughout the study of Histology to make a distinction between the cells which are vitally active and those which serve chiefly or wholly some mechanical end; and hence attention must be called at the outset to the means by which the living matter of the cell can be identified.

120. **Protoplasm** exists in all young cells — for instance, in the soft cone of tissue in buds, in root-tips, and other points of growth — as a nearly transparent or finely granular substance.[1] It completely fills the interior of very young cells, but with increase of the cells in size there arise cavities (*vacuoles*) containing sap, and these by their enlargement and confluence may appear to occupy the entire space within the cell. If, however, such a cell be acted upon by anything which causes contraction

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(2) Make a thin section through the petiole of a begonia or some common house-plant, and observe the granules imbedded in the protoplasm (*chlorophyll-granules*); notice also crystals, either in masses or single.

(3) Examine a thin section through dry pine wood, test with iodine, and observe the absence of protoplasmic matters. Examine in the same way any hard wood.

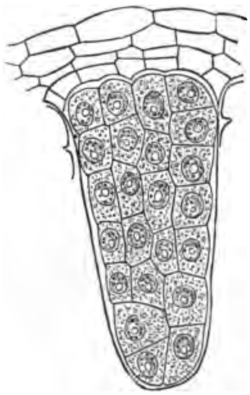
(4) Make a section through any starchy seed, for instance a common bean, and treat it with a solution of iodine; notice the distribution of protoplasmic matters in the form of thin irregular films throughout the cells. Examine a similar section in oil, and see what differences, if any, can be detected. Probably the presence of *protein granules* will be made out.

From these preliminary examinations a beginner will have demonstrated the protoplasmic matter in its active, resting, and reserve states; he will have seen chlorophyll, the nucleus, and starch, the chief form in which food is stored in plants. He will also have seen a few of the more common crystals.

After such a study the student is urged to examine practically the characteristics of the cell-wall and the cell-contents as they are presented in this chapter.

[1] By the use of staining agents, especially hæmatoxylin, protoplasm can in many cases be shown to possess a complicated mesh of very delicate fibres,

of the protoplasm,[1] as, for instance, a solution of common salt, the protoplasm separates from the cell-wall, and by its contraction shows clearly that it is a closed sac. At a later stage in some cells even this thin protoplasmic sac wholly disappears.



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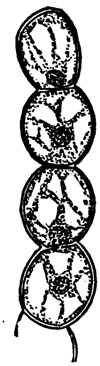
121. Protoplasm itself must be regarded as essentially transparent and colorless, but it is seldom found without some admixture of other matters, which give it a granular appearance. The granules are generally very small, and as a rule are not found at the periphery of the mass. The limiting surface of the protoplasmic mass is further distinguished by being somewhat denser and firmer than the substance it encloses; and although it cannot be separated from the latter by mechanical means, it is often spoken of as a film;[2]



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which take up the coloring matter readily, leaving the remainder of the mass unstained. It is believed by Schmitz that the unstained mass is a homogeneous liquid filling the meshes (Sitzungsber. der niederrhein. Gesellschaft in Bonn, 1880).

[1] Such substances are termed *plasmolytic* agents.

[2] Of the appearance of protoplasm, the following remarks by Mohl, who first gave it the name in 1846, are of interest. "If a tissue composed of young cells be left some time in alcohol, or treated with nitric or muriatic acid, a very thin, finely granular membrane becomes detached from the inside of the wall of the cell in the form of a closed vesicle, which becomes more or less contracted, and consequently removes all the contents of the cell, which are enclosed in this vesicle, from the wall of the cell. Reasons hereafter to be discussed have led me to call this inner cell the *primordial utricle*. . . . In the centre of the young cell, with rare exceptions, lies the so-called *nucleus cellulæ* of Robert Brown. . . . The remainder of the cell is more or less densely filled with an opaque, viscid fluid of a white colour, having granules intermingled in it, which fluid I call *protoplasm*" (Mohl: The Vegetable Cell, Henfrey's Translation, 1852, pp. 36, 37).

FIG. 1. From developing anther of Orchis maculata, showing young cells completely filled with protoplasm. Observe also the nucleus with its nucleolus, in each cell. (Guignard.)

FIG. 2. A hair from the stamen of Tradescantia pilosa, showing the protoplasm in the form of granular threads running from side to side of the cell-cavity. The white spaces between these threads are vacuoles. The nucleus can also be seen in each of the four cells. (Jacobs.)

and where there is any break in the continuity of the mass, for instance in the case of sap-cavities, a similar limiting film may be supposed to exist.

122. The consistence of protoplasm depends on the amount of water which it contains. Thus in dry seeds it is nearly as tough as horn, while in the same seeds during germination it becomes like softened gelatin. It absorbs water readily and becomes permeated by it, thereby increasing its apparent fluidity, but it never becomes a true fluid. Moreover, there is a limit to the amount of water which it takes up.

123. Chemically considered, protoplasm is a very complex substance. It belongs to a group of bodies of which the albumin of egg may be conveniently taken as the type. Owing to their many slight but sometimes remarkable changes, they have been collectively termed proteids. The terms *albuminoids* and *proteids* may be used interchangeably.

124. The albuminoids, or proteids, which form with water the bulk of protoplasm proper, are of course associated with the matters which this living substance makes, uses, and discards. But these matters exist in the protoplasm in very different proportions at different times, though never in such amount as to obscure the peculiar reactions of the albuminoids. These are the following: 1. The yellow or brownish color imparted by solutions of iodine. 2. The purple color produced when the specimen first saturated with a solution of cupric sulphate is acted on by potassic hydrate. 3. The rose color, often faint, which follows the successive action of a solution of sugar and strong sulphuric acid. 4. The red color given by Millon's reagent. This test generally requires the cautious application of heat. 5. The purplish color from prolonged action of hydrochloric acid.

125. Dilute solutions of the caustic alkalies dissolve protoplasm; concentrated solutions do not. If a young cell is acted on by concentrated potash, its protoplasm is not essentially affected; but if water is now added, the protoplasm dissolves at once.

126. The spherical or ellipsoidal mass found in the protoplasm of active cells, and differing from the rest of the protoplasm in its greater density, is the *nucleus*. The sharply defined point often seen in the nucleus is the *nucleolus*.

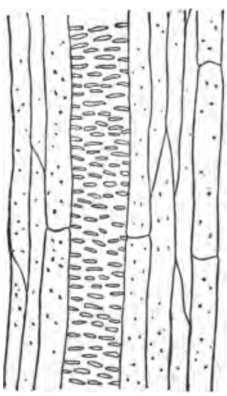
127. The nucleus undergoes remarkable changes during the earliest stages of the cell, which will be described in the chapter on "Growth." The relations which exist between the proto-

plasm in one cell with that in contiguous cells will be considered in Chapter VI.

128. **The cell-wall.** The cell-wall is produced from materials contained in protoplasm,[1] and is laid down in intimate contact with it, as an even homogeneous film which exhibits at first no obvious structure, but with increase in size generally becomes modified in appearance, consistence, and composition.

129. Its evenness of surface is in most cases early lost by addition of new matter, giving rise to protuberances or markings of different sorts. Though at first possessing no evident structure, it may become clearly differentiated into layers, and thus become stratified, or striations may appear. Its consistence, at the outset that of the most delicate bleached linen fibre, may soon become changed, on the one hand to that of soft gelatin, or on the other to that of the densest wood. Moreover, although devoid of color when first produced, it may acquire distinct coloration; and, lastly, its chemical character may undergo such important changes that its normal reactions are no longer given.

130. **The markings of the cell-wall.** Uniform thickening of the whole cell-wall is extremely rare; even in the examples which are commonly given to illustrate it, pores or channels, more or less distinctly visible, interrupt its continuity.



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131. The thickenings may possess great irregularity, or they may be so strictly localized and regular as to form characteristic features of the widest use in diagnosis. They may project outwardly, forming ridges, spines, and other sculpturings; or, as is most commonly the case, inwardly, giving rise to rings, spirals, etc.

132. If the wall is thickened throughout, except at well-defined points, depressions or pits are produced, varying considerably in outline, but occurring generally as simple dots or lines. In some cases it is not difficult to see that these dots or lines are true pores or fissures running from one cell to the next.

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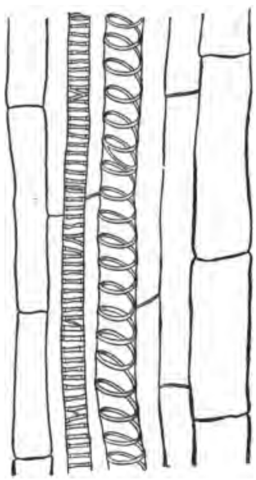
[1] According to Schmitz, the cell-wall is produced by the conversion of the limiting film of protoplasm into cellulose. That the cell-wall is formed *at* the limiting film admits of no question.

FIG. 3. Pitted duct; from stem of Cichorium Intybus. (Jacobs.)

133. Bordered pits are a very common modification of the last. A comparatively large spot remains unthickened, but becomes covered by a low dome which has at its top a small aperture; at a corresponding point of the wall of the neighboring cell another thickening produces a similar dome, so that the two domes constitute a double convex body which appears as a disc with a central perforation. These bodies are known as discoid markings.

134. Sometimes the spot covered by the arched projection or dome is elliptical instead of round. When this kind of marking becomes linear, or nearly so, it is termed scalariform.

135. When annular and spiral thickenings occur the cell-wall lying between them remains so thin that a slight strain suffices to break it, releasing the rings and coils. The number, the direction, and the steepness of the spirals furnish in some cases diagnostic features.



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136. Besides spirals and rings, there are intermediate forms, which pass easily over into netted or reticulated thickenings. It happens sometimes that the reticulated markings are so regular that their interspaces appear as regular polygons.

137. The external sculpturing of the cell-wall can be seen in many pollen-grains, and in the hairs of many plants, though in the latter case the projections may be partly due to irregularities in the form of the cell.

138. **Stratification and striation.** The cell-wall, even at an early stage, frequently exhibits a distinctly stratified structure. In some cases, at least, removal of all the water which forms a constituent of the wall obliterates every trace of stratification, and this fact supports the hypothesis that the appearance of lamination is caused by differences in the amount of water contained in alternating layers of the wall. The less strongly refractive layers are supposed to contain more water than those which are highly refractive. But there are cases of stratification

FIG. 4. Annular and spiral markings; vertical section through stem of Tradescantia pilosa. (Jacobs.)

which cannot be satisfactorily explained by this hypothesis. There are, besides, numerous instances in which the stratified appearance is not clearly shown until the cell has been acted on by an acid or an alkali; a good example of this is afforded by the firm cells of the albumen of the vegetable ivory (Phytelephas).[1]

139. An appearance of spiral striation,[2] ascribed also to the unequal distribution of water, is often seen, especially in the cells of the liber of Apocynaceæ and allied orders, and in many wood-cells. The striations are not constant as regards the steepness of the spiral; in fact, in a few instances rings instead of spirals are present. A striated appearance is sometimes presented in walls which have been deprived of all their water.

140. Chemically considered, the young cell-wall consists essentially of cellulose, a substance which has the same percentage composition as starch, namely, $C_6H_{10}O_5$. Even in its purest state it is associated with a trace of mineral matters which remain behind as ash when it is burned, and in the living cell it is always permeated by water.

141. **Cellulose** is not soluble in any of the following liquids commonly used in microscopic manipulations, — water, alcohol, glycerin, dilute alkalies, and dilute acids. It is, however, more or less strongly acted on by hot concentrated alkalies, without passing into true solution, and it is apparently dissolved by strong sulphuric acid. Whether cellulose becomes truly dissolved by concentrated sulphuric acid, or merely forms some other carbohydrate under its action, is of little consequence, so far as the destruction of cell-walls is concerned. In nearly all cases its action is so energetic that the wall of a cell can be

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[1] As shown by Mohl, the action of a mineral acid of proper degree of concentration causes the wall to swell up, and the lamellar structure becomes very distinct. "By this means the lamellar structure may be demonstrated even in those cases in which the unaltered membrane appeared completely homogeneous" (Mohl: Vegetable Cell, p. 10).

[2] "The stratification is visible on the transverse and longitudinal sections of the cell-wall, the striation on the surface as well; it is usually most evident there, but is in general less easily seen than the stratification; it depends on the presence of alternately more or less dense layers in the cell-wall, meeting its surface at an angle. Generally two such systems of layers may be recognized mutually intersecting one another. There are thus all together three systems of layers present in cell-wall: one concentric with the surface, and two vertical or oblique to it mutually intersecting, like the cleavage planes of a crystal splitting in three directions (Nägeli); and just as this cleavage is sometimes more evident in one direction, sometimes in another, so it is also with the stratification and striation" (Sachs: Text-book, 2d Eng. ed., p. 20).

wholly removed by this acid, even without destroying the protoplasmic contents; and this fact has been extensively employed in the examination of the continuity of the protoplasm in contiguous cells.[1]

142. The only known solvent from which cellulose can be recovered without change of composition is Schweizer's reagent, ammoniacal solution of cupric oxide. In this liquid, cellulose swells considerably, and slowly disappears. It is thought by some chemists that it does not truly dissolve. From its apparent solution, it can be precipitated in the form of a flocculent mass by acids, salts of many kinds, and even by the addition of a large amount of water (see 55).

143. Freshly prepared aqueous and alcoholic solutions of iodine do not color pure cellulose beyond giving a faint yellowish tint; but if the reagents have been kept for some time, particularly in the light, they may impart a blue color.[2] The latter

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[1] Unsized, well-bleached linen paper is nearly pure cellulose. If it is dipped in a cold mixture of one volume of water and two volumes of strong sulphuric acid, withdrawn after ten to twenty seconds, and washed thoroughly in water, and finally in dilute ammoniacal water, it becomes much like parchment. This "vegetable parchment" is a suitable membrane for certain experiments in absorption. The acid in this experiment is supposed to convert at least a portion of the cellulose into a substance which closely resembles starch in its chemical reactions, termed *amyloid.* Parchment paper can be made also by concentrated zinc chloride, and by a few other agents.

[2] Mohl (The Vegetable Cell, p. 24, Eng. Trans.) says: "When imbued with iodine, it becomes indigo-blue if wetted with water." In a note on pages 28 and 29, he further says: "My researches shewed me that the influence of sulphuric acid was by no means necessary for the production of the blue colour in membranes which are not strongly incrusted, as in the parenchymatous cells of succulent organs, but that iodine and water alone are sufficient; while in full-grown and hardened cells sometimes the primary membrane alone, sometimes even a greater or smaller portion of the secondary layers had through the deposition of foreign substances, altogether lost the property of becoming blue on the application of sulphuric acid and iodine, although they were still composed of cellulose, and iodine alone would very readily produce a blue colour in all their membranes after the infiltrated matters had been removed. The means I employed to remove the infiltrated substances were caustic potash and nitric acid. . . . After this treatment, the whole of the layers of all elementary organs are coloured a beautiful blue by iodine even when they offer so great a resistance to the action of sulphuric acid before the treatment with nitric, as is the case in the outer membrane of wood-cells and of vessels, and in the brown cells at the circumference of the vascular bundles in Ferns."

It is plain that, in the latter cases, the cell-wall had been very powerfully acted on before the application of the iodine, and to this severe preliminary treatment may be ascribed the efficiency of the latter in producing the blue color.

color, however, is given even by fresh solutions of iodine to cellulose which has been previously treated with certain chemical agents, for instance, strong sulphuric acid. A convenient method of employing this reaction as a test for cellulose is to thoroughly moisten the object with a dilute solution of iodine, and then to apply strong sulphuric acid, upon which the cellulose immediately turns bright blue. It is sometimes advantageous to dilute the sulphuric acid employed, either with water or with glycerin; but for most cases the concentrated acid is the best.

Schulze's solution of iodine, better known as chloroiodide of zinc, used alone, gives with pure cellulose a blue color inclining to purple. This reaction, though not always so prompt as the other, is generally more manageable, and, on the whole, more satisfactory.

In a few instances the cell-membrane becomes yellowish-brown throughout, upon the application of an iodine solution, a reaction which might be easily mistaken for that which albuminoids give; that the color, however, is not here due to their presence, appears on subjecting the tissue to the action of Millon's reagent. Vertical sections of the stem of Begonia, as noticed by Nägeli, afford an instructive example of this.[1]

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[1] That the yellow color imparted by iodine has been otherwise interpreted, will appear from the following: —

Harting (Ann. des Sc. nat., sér. 3, tome v. p. 328) states, that "all lignified cells have Protein matters in their walls."

Mohl (The Vegetable Cell, p. 25) says: "Nitrogenous compounds do not occur in the membranes of cells which are just at the commencement of their development, for these are not coloured yellow by tincture of iodine, yet hardly a full-grown cell is met with in which this is not the case."

It is held by Nägeli that vegetable cell-membranes consist, in some instances, of two isomeric substances, unequally soluble, which are intimately commingled. One of these is soluble in cold water, more easily in hot water, and sometimes needs for its complete extraction a dilute acid. From the solution iodine throws down a blue or bluish-green precipitate.

A synoptical table, based on differences in solubility of cellulose and its modifications, and in their behavior towards iodine, has been constructed by Nägeli. The part of the table which is given below affords excellent practice for the beginner.

I. Differences in Solubility.

(1) In cold water, becoming swollen; in hot water, disappearing, *vegetable mucilage; e. g., in the outer layer of the cells forming the testa of quince seeds and those of flax.*

(2) Soluble in concentrated sulphuric acid, and in cuprammonia; *e. g., cotton-hairs, bast-fibres,* etc.

144. The principal modifications of the cell-wall are the following: —

(1) Partial or complete conversion into mucilage (Gelatination); (2) Lignification; (3) Cutinization (or Suberification); (4) Mineralization.

145. All of these, except the first, change the chemical character of the cell-wall only by what may be regarded as infiltration; upon removal of the infiltrated matter by means of proper agents, the cellulose basis of the wall is left behind with very little if any change.

146. It sometimes happens that one part of the membrane of a cell, or even one of its layers, may be modified in one way, and another in another; it is also possible for the same membrane to undergo two of the changes above mentioned; namely, Lignification and Mineralization.

147. **The mucilaginous modification.** Commonly the cell-wall is not much changed by immersion in water. It may become more nearly transparent, but its size and density are not essentially

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(3) Soluble in sulphuric acid, insoluble in cuprammonia (unless previously acted on by acids or alkalies); *e. g.*, *the pith*, and *medullary rays of woods.*

(4) Soluble in concentrated sulphuric acid; insoluble in cuprammonia, but becoming soluble in this upon previous treatment with Schulze's macerating liquid; *e. g.*, *wood-cells of pine*, *oak*, *yew*, etc.

(5) Insoluble in concentrated sulphuric acid and cuprammonia, but soluble in boiling concentrated potassic hydrate; *e. g.*, *cuticle*, and *the outer layer of the membrane of older ducts.*

II. Iodine Reactions.

(1) With iodine and water, a blue color: *lichen-filaments*, etc.

(2) With iodine and water, no color; but giving a blue tint with iodine and a metallic iodide; or when iodine is followed by sulphuric acid: —

A. *Thin-walled Parenchyma* (which will often turn blue when a pure iodine solution acts with repeated drying), *older Parenchyma*, *the inner part of thickened wood-cells of Pinus and Abies*, and *the bast-fibres of hemp.*

B. Only when the reagents have been preceded by the application of nitric acid: *all membranes in the interior of the plant*, *e. g.*, the outer part of wood-cells and ducts, the brown cells which surround the vascular bundles in ferns, etc.

C. Only when the reagents have been preceded by the use of boiling potassic hydrate: *cork*, etc.

According to Frémy and Urbain, the substances which form the skeleton of plants are principally pectose and derivatives from it, cellulose and its isomers, vasculose, and cutose. These four groups are thus distinguished from one another.

Pectose acted on by alkaline carbonates is changed into pectic acid, and

affected. It sometimes happens, however, that the cell-wall acquires wholly new relations to water, and becomes capable of absorbing a large amount of it with great increase of volume and translucency. A cell-wall which has undergone this mucilaginous modification takes on, when placed in water, the consistence of soft gelatin, and if the mass is then warmed it appears to dissolve, forming a thick mucilage. Upon drying, the mucilage hardens into a translucent gum, in which the cellulose character is nearly or wholly lost.

148. Generally the changes produced in such a wall by water are so rapid that it is desirable to place the specimen at first in alcohol, and then to replace this medium cautiously by water or by dilute glycerin, when the variations in shape, size, and consistence can be easily followed. The addition of alcohol will of course arrest the changes at any stage desired.

149. These changes can be easily traced in the outer cells of the integument of a flax-seed. The mucilage appears as an obscurely stratified mass nearly filling the cells, except at their centre, where there is a low-arched cavity. On the cautious

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pectates are formed. These are readily decomposed by hydrochloric acid, and insoluble gelatinous pectic acid is thrown down.

Cellulose and its isomers agree in being soluble in concentrated sulphuric acid, but they differ in the following points: Cellulose dissolves at once in cuprammonia; paracellulose, only after the action of acids; metacellulose, not even then.

Vasculose is not easily soluble in concentrated sulphuric acid, but after the action of oxidizing agents gives rise to resinous acids, which are separable by alkalies from associated cellulose.

Cutose, the transparent film covering the aerial organs of plants, is dissolved neither by concentrated sulphuric acid nor by cuprammonia, but dissolves without change in alkaline liquids. The following results of analyses by Frémy and Urbain (Ann. Sc. nat. bot., 1882) show approximately the amount of these substances in different parts of certain plants.

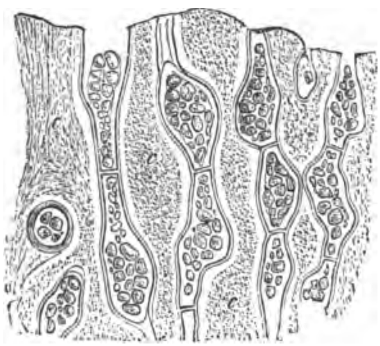
Root of Paulownia. — (1) Substances soluble in water and in dilute alkalies: cork 45, soft bast 56, body of root 47. (2) Vasculose: cork 44, soft bast 34, body of root 17. (3) Paracellulose: cork 4, soft bast 4, body of root 30.

Stems. — Vasculose increases in amount with the density of the wood. The pith contains: of cellulose 37, paracellulose 38, vasculose 25 per cent. Cork contains: matters soluble in acids and alkalies 5, cutose 43, vasculose 29, cellulose and paracellulose 12 per cent (cutose and vasculose forming together the subérine of Chevreul).

Leaves of Ivy. — Water and substances soluble in neutral solvents 707.7, parenchyma (formed of cellulose and pectose) 240, fibres and vessels (of vasculose and paracellulose) 17.3, epidermis (cutose and paracellulose) 35 parts.

Petals of Dahlia. — Water and soluble matters 961.30, parenchyma (of cellulose and pectose) 31.63, vasculose 1.20, paracellulose 2.27, cutose 3.60 parts.

addition of water, this cavity becomes more clearly defined, the whole mass of the cell swells, and the mucilage can then be made out as a distinctly stratified structure belonging apparently as much to the outer as to the inner face of the cell-wall. But if the action of water is prolonged, the stratified appearance vanishes, and the wall becomes optically homogeneous, with the exception of its middle portion, the so-called primary membrane, which remains unchanged. On the addition of iodine and sulphuric acid, the primary membrane, but not the mucilage, becomes blue. Furthermore, the lateral walls of the cells are not converted into mucilage.



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150. The mucilaginous modification can be examined to advantage in the seeds of some Polemoniaceæ (especially Collomia) and a few Acanthaceæ, *e. g.*, Ruellia. These seed-coats are covered with hairs which break open when wet, and allow not only the mucilage but also slender coiled threads to escape. The achenes of some Compositæ of the Senecio group and the nutlets of a few Labiatæ (the Salvia tribe) exhibit nearly the same phenomenon.

151. **Lignification.** Induration of the cell-wall is caused most commonly by the presence of an incrusting substance known as lignin. Owing to the difficulty of separating it from the cellulose, with which it is associated, its chemical composition must be regarded as uncertain. Although generally spoken of as a single substance, it is probable that the lignin, or incrusting matter, is made up of several different substances,[1]

[1] Payen (Mém. des savants étrangers, ix., 1846, pp. 68, 5) distinguished four such incrusting matters, differing in their composition and in their behavior to solvents. *Lignose:* insoluble in water, alcohol, ether, and ammonia; soluble in solutions of potassa and soda. *Lignone:* insoluble in water, alcohol, and ether; soluble in ammonia, potassa, and soda. *Lignin:* insoluble in water and ether; soluble in alcohol, ammonia, potassa, and soda.

Fig. 5. Section of the albumen of Ceratonia siliqua, showing mucilaginous modification. (Sachs.)

which occur in different proportions in different plants and in different parts of the same plant.

152. Lignin dissolves readily in Schulze's macerating liquid and in potassic hydrate, but not in cuprammonia, the well-known solvent for cellulose.

153. By the use of Schulze's macerating liquid a lignified cell-wall can be wholly freed from its incrusting substance, and pure cellulose will be left behind. For control, it is well to employ the tests for lignin given below, both with ordinary wood and with similar specimens which have been treated with this solvent.

154. *Tests for lignin.* 1. Salts of anilin. If a lignified cell-wall is subjected to the action of a strong solution of anilin sulphate acidulated with sulphuric acid, or to that of a solution of anilin chloride acidulated with hydrochloric acid, it will at once turn yellow. The depth of the color depends somewhat upon the strength of the solution. The color is destroyed by alkalies, but is restored by acids. Wiesner, who first applied the foregoing reagents to the detection of lignin, has suggested another which is for many cases even more satisfactory; namely, 2. Phloroglucin. In an alcoholic or aqueous solution of this substance (.01 per cent) a lignified cell-wall does not change color; but if the specimen is slightly acidulated with hydrochloric acid, it becomes violet or purple. 3. Carbolic acid (phenol) and hydrochloric acid. The solution described on page 11 imparts to lignified cell-walls, when exposed to a strong light, a green color which is very fugitive. Specimens under examination should therefore be watched from the moment that the reagent reaches them. 4. Indol. An aqueous solution is to be replaced under the cover-glass, after it has moistened the specimen thoroughly, by a little dilute sulphuric acid; lignified cells will become red or reddish-violet. This reagent does not appear to have

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Lignirèose: soluble in all the solvents mentioned above, but only to a slight extent in water.

CHEMICAL COMPOSITION.

	Carbon.	Hydrogen.	Oxygen.
Lignose	46.10	6.09	47.81
Lignone	50.10	5.82	44.08
Lignin	62.25	5.93	31.82
Lignirèose	67.91	6.89	25.20
Cellulose (of cotton)	44.35	6.14	49.51

According to Franz Schulze, the probable composition of lignin is: Carbon, 55.55; Hydrogen, 5.83; Oxygen, 38.62.

any marked advantage over that which gives nearly the same color, namely, phloroglucin.

155. By the employment of these reagents many cell-walls have been shown to be distinctly lignified when the older reagent — iodine in solution — failed to detect the change.

156. **Cutinization.** Ordinary and lignified cell-walls, and those which have undergone the mucilaginous modification, absorb water freely. On the other hand, the walls of certain cells found chiefly on the exterior of organs are repellent. The substance which imparts the repellent character to the cell-wall is known as cutin; when restricted to cork it is called suberin.

157. Cutin and suberin have been described as different substances; but although the former is more generally associated with waxy matters, its reactions are essentially the same as those of suberin. The water-proofing of the cell-wall may be superficial, as in most young epidermal cells, or it may affect the whole structure of the wall, as in the case of cork. If a distinction is made between the two states, the first may be termed cutinization, the second, suberification.

158. Cutin can be removed from the walls with which it is associated, by the use of Schulze's macerating liquid, subsequent treatment with potassa, and careful washing. It is sometimes necessary to heat the section in potassa before the cellulose can be completely freed from the other matters.

159. Höhnel[1] has shown that the wall of a cork-cell, with the exception of the young cork-cells in Coniferæ, is composed of five plates: (1) a middle plate, common to the two contiguous cells; (2) two plates, one on each side of the latter, consisting of cellulose which is both cutinized and lignified; (3) two plates of cellulose forming the inner lining of the respective cells. The latter plates may be more or less lignified. Differences in the relative proportions of these constituent plates give rise to differences in the character of different kinds of cork.

160. As in the case of lignin, the difficulty of extracting cutin renders its chemical composition doubtful. It is usually given as follows: —

Carbon	73–74 per cent.
Hydrogen	10 "
Oxygen	17–16 "

But there is also a trace of nitrogenous matter demonstrable; this probably belongs to residual protein matters which are in

[1] Sitzungsber. d. k. Akad. Wien, Bd. lxxvi. 1 Abth.

the cell-cavity, and not in the cell-wall. Sulphuric acid and chromic acid, even when concentrated, produce little effect on cutinized membranes, beyond removing traces of cellulose present in the cell-wall. The latter acid, however, increases the transparency of cutinized membranes, especially after prolonged action.

161. Potassic hydrate softens such membranes and colors them yellow; when heated it breaks them into a granular mass which may be removed by careful washing. Cautiously heated with Schulze's macerating liquid, they disintegrate into granules of ceric acid, — a substance which dissolves in alcohol, ether, and benzol. Several of the coal-tar colors stain the cutinized portions of cell-walls very deeply; if the specimen thus colored is placed in absolute alcohol, the cutinized parts alone remain colored.[1] Two points relative to the cutinization of epidermal cells may be noted: (1) the cutin may take on the form of layers, often numerous and conspicuous; (2) there may be a considerable irregularity in the outline of the deposits, sometimes as folds, hooks, and the like, which do not strictly conform to the cellulose wall on which they arise.

162. **Mineralization of the cell-wall.** Although all cell-walls, even the most delicate, can be shown to contain traces of inorganic matter, it is only in a few special cases that such substances appear in a form to be noticed under the microscope. Mineralization of the wall may be general or local, may depend upon the presence of crystals or of amorphous deposits, and these may consist of silicic acid or of calcium salts.

163. General mineralization of the wall depends most frequently on silicic acid, and may be best demonstrated by first boiling the specimen in nitric acid, drying, heating to redness on platinum-foil, and, lastly, treating again with nitric acid. The silicic acid remains behind as a delicate skeleton which copies in all particulars the contour of the wall of which it formed a part. Fine examples are afforded by the harder grasses.[2]

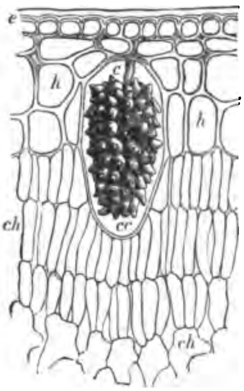
Calcium salts may exist in crystalline or amorphous form, and may be distinguished by the tests to be given for them under the section on "Crystals." That in some cases they constitute an integrant part of the wall itself admits of no question.

164. In the cells of many plants, especially Urticaceæ, pedicellated concretions occur, which, on superficial examination,

[1] Olivier: Bull. Soc. bot. de Fr., 1880, p. 234.

[2] *Tabasheer* consists of the siliceous substances which occur in the joints of bamboo in large quantities.

appear to be much like the sphere-crystals described in 186. But if they are carefully treated with dilute hydrochloric acid, the chief part of the concretion disappears, leaving behind a delicate trace of cellulose which was intermingled with it. That this cellulose was an intrusive growth into the cell from the wall, is shown by a study of its development. In most cases such concretions (Cystoliths) are plainly stalked, but in some instances they are only obscurely stalked, and are with difficulty distinguished from the ordinary cell concretions. In the leaf of Ficus elastica (see Fig. 6) they are more completely developed than in any other common plant.



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165. Other changes, chiefly those of degradation, may take place in the cell-wall, giving rise to products variously known as gums, resins, &c.; but in all these cases there is such a commingling of the cellulose derivatives with those formed from the contents of the cell, that they cannot be readily distinguished.

166. Protoplasm, as was shown in the previous sections, gives rise upon its exterior to the cell-wall. Inside the cell, likewise, it produces, either directly or indirectly, various substances. In the present chapter these substances are to be considered only so far as relates to their detection and identification. Most of them are to be examined later, with reference to their office in the life of plants.

167. **Plastids.** In the protoplasm of active cells certain granules having substantially the same chemical and, with the exception of their color, the same physical properties as protoplasm, are clearly differentiated. They are imbedded in the general protoplasmic mass, and are not separable from it by mechanical means.

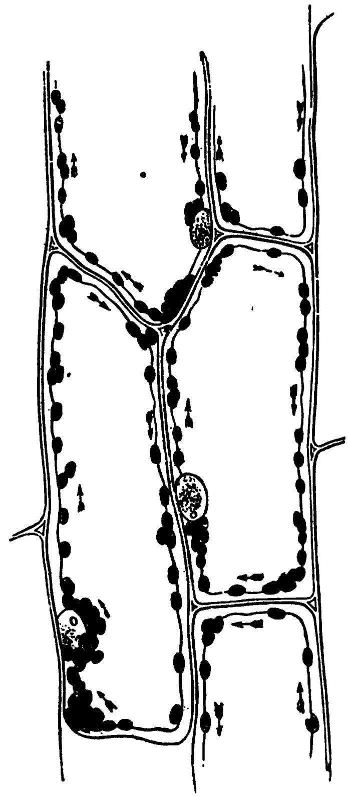
168. Such granules may be conveniently referred to three types,[1] depending upon the color: (1) those which are green, —

[1] Recent investigations render it probable that these three kinds of granules are derived from a common source, and although hardly distinguishable from

FIG. 6. Cystolith from the upper part of a leaf of Ficus elastica. *e*, epidermis; *h*, hypoderma; *c c*, cystolith; *ch*, *ch*, cells containing chlorophyll. It will be observed that the pedicel of the cystolith appears to be attached to the lower wall of the upper epidermal cells.

Chloroplastids, or chlorophyll granules, also called chloroleucites; (2) those which have some color other than green,—*Chromoplastids*, or chromoleucites; (3) those which are devoid of color,—*Leucoplastids*, or leucites.

169. *Chlorophyll Granules*, or *Chloroplastids*, are met with in the green parts of all plants; in fact, to them the green color is due. But they are sometimes masked by the presence of color in the cell-sap. Their shape is spherical or spheroidal, and somewhat flattened. They have an average diameter of 2 to 5 μ, but many granules are considerably larger than this. It frequently happens that they become of great size, owing to the presence of solid contents,—for instance, starch,—which may accumulate in large amount.



170. If the granules are subjected to the action of alcohol, their coloring matter is wholly removed; but they retain their former volume and shape, appearing faintly outlined in the protoplasmic mass in which they are imbedded. Hence it is proper to distinguish between the chlorophyll body of the chloroplastid and the chlorophyll pigment which imparts to it its characteristic color.

The chlorophyll body may be shown, by the process described in 61, to be somewhat spongy in structure, and to have on its

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each other at the outset, become chloroplastids, chromoplastids, or leucoplastids, according to the part which each is to play. Moreover, one kind of granule can, under certain conditions, perform work which properly belongs to another, and hence it is not always easy to identify the different kinds. In most cases, however, their discrimination is very simple.

They are also called, collectively, **Chromatophores.**

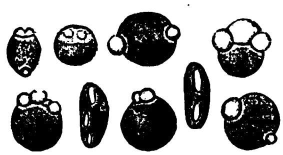
FIG. 7. Chlorophyll granules in the leaf of Vallisneria spiralis. $\frac{450}{1}$. (Weiss.)

exterior a delicate film. Meyer believes that the coloring matter takes the form of grains of extreme minuteness which are interspersed through the whole substance, while Tschirch holds that the pigment, dissolved in a liquid similar to the ethereal oils, is diffused through the mass.

171. If starch is present in large amount in chloroplastids, iodine causes at once a deep bluish-brown color; but if the starch is not very abundant, the characteristic blue reaction is concealed by the yellow produced by the protein reaction of the protoplasm. Hence it is well, after having removed the chlorophyll pigment by alcohol and subsequent washing with water, to treat the specimen with moderately strong potassic hydrate in order to dissolve the protein matters. If this has been well done, and the specimen carefully freed from the potash, the protoplasmic mass and its imbedded granules will seem to have completely disappeared; but the skilful use of oblique illumination will show that an undissolved trace of something having the former contours remains behind. Application of iodine brings out minute blue points where the granules were.

Chloral hydrate of the strength recommended in 53 may replace potassic hydrate in this examination.

172. The starch in chlorophyll granules is sometimes wholly within the granule; but it is occasionally — especially in the case of flattened granules — found on their exterior, forming a noticeable protuberance.



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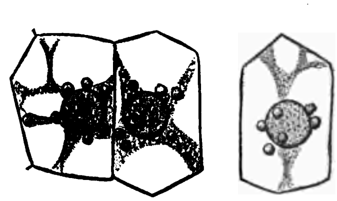
173. When a plant containing chlorophyll granules is kept for a time in darkness, the production of starch is arrested; and if other forms of activity continue, even that starch which has already accumulated in the granules soon disappears. Furthermore, the color of the granules is changed from green to yellow; and if the change is not arrested at this point by bringing the plant again into the light, all the granules will break up and become apparently merged in the

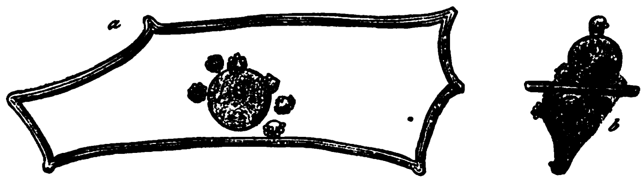


9 *a*

FIG. 8. Chlorophyll granules with protruding starch-grains. From the cortex of Philodendron grandifolium. $\frac{850}{1}$. (Schimper.)

FIG. 9 *a*. From the epidermis of Philodendron grandifolium. Young cell with amylogenic bodies newly formed. $\frac{850}{1}$. (Schimper.)

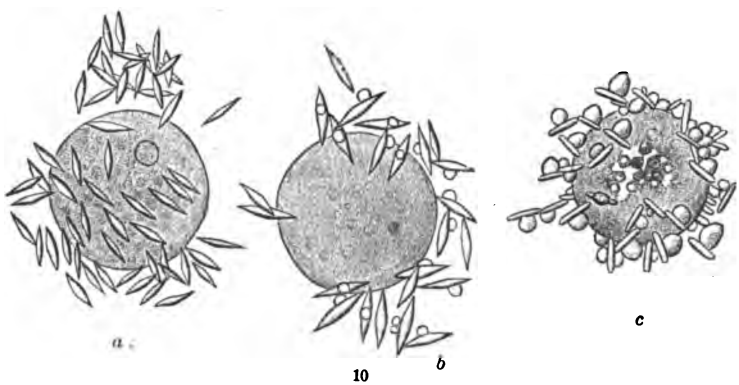
general protoplasmic mass of the cells, being no longer recognizable. Those, however, which have been changed no further



9 b

than by loss of color, closely resemble another kind of granule; namely, leucoplastids. (For exceptions see Chapter X).

174. *Leucoplastids.* These are found in parts which are normally devoid of chlorophyll, such as tubers, rhizomes, etc.



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They may be wholly colorless, or faintly tinged with yellow, and hence are apt to escape detection. They may be considered as the points around which starch accumulates when stored for the future needs of the plant. Schimper,[1] who first accurately described them in all their relations, terms them "starch generators;" they are also known as *amylogenic* bodies, which of course means the same thing. They are seen to the best advan-

[1] Schimper: Bot. Zeit., 1880, 1881, 1883.

FIG. 9 *b*. Same, more advanced: *a*, the amylogenic bodies are covered with starch-grains; *b*, two nuclei on a cell-wall, each surrounded by amylogenic bodies covered by starch. $\frac{850}{1}$. (Schimper.)

FIG. 10. *a*, Young amylogenic bodies surrounding the nucleus of a cell in the root of Phajus grandifolius; *b*, same, with starch-grains developing; *c*, same, more advanced. $\frac{850}{1}$. (Schimper.)

tage in thin sections of many starchy tissues, by the use of dilute tincture of iodine, which colors them more or less deeply yellow. Millon's reagent colors them red.

Owing to the minuteness of the leucoplastids, the following explicit directions by Strasburger will aid in their detection: Make thin longitudinal sections through the upper part of a young pseudobulb of Phajus grandifolius, taking care that the cut extends to its green surface. Immediately place the sections in an alcoholic solution of iodine diluted with one half its volume of water. (Picric acid may be advantageously used instead of the iodine solution.) In good preparations the leucoplastids will be seen in the inner part of the section as small staff-shaped bodies which, at the first glance, appear to be homogeneous, but are afterwards recognized as somewhat granular in structure. The section is next to be examined nearer its outer part, and it will then be seen that the bodies there possess a green color, are larger, and lenticular in form. They are also plainly porous, their increase in size being apparently associated with a sponginess of their substance. Their size diminishes towards the outer cellular layers, they become somewhat rounded, and finally take the familiar form of chlorophyll granules. Prismatic colorless protein crystals are frequently associated with these bodies. In sections which are placed in water, the leucoplastids disappear almost instantaneously, and even the chlorophyll granules soon begin to disorganize, while the swollen protein crystals then appear as colorless parts of the latter.

In the rhizome of Iris Germanica the sections for examination must be taken parallel to the surface. In uninjured cells the leucoplastids appear as collections of protoplasm at the end of each starch-granule. If the section is in water, the leucoplastids become granular and finally break up into minute granules which show the Brownian or molecular movement.[1]

Chromoplastids, or the color-granules which occur abundantly in flowers and fruits, will be specially treated later.

175. **Protein granules.** The protein matters in plants have been divided into two classes: (1) the *active*, such as active protoplasm, the nucleus, etc.; (2) the *reserve*, which can change their dormant condition and become active when occasion demands. Inactive, amorphous protoplasm, as it sometimes exists in certain cells, where it is simply a tough shapeless mass, does not need further consideration at present; the reserve matters

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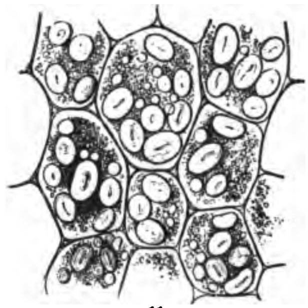
[1] Strasburger: Das botan. Practicum, 1884, pp. 67, 68.

now to be examined being those which take the form of more or less regular grains. These which are known as

176. Protein granules may be either independent, or associated with other substances. In nearly all cases they are more or less soluble in water, and hence require special treatment for their satisfactory examination. Cells supposed to contain them may be placed for examination in any fixed oil, and the granules will remain unchanged. A more practicable method of treatment is suggested by Pfeffer; namely, to subject the granules to the action of an alcoholic solution of mercuric chloride, by which they are rendered insoluble (see 63). The solution is made by dissolving one part of mercuric chloride (corrosive sublimate) in fifty parts of absolute alcohol; in this solution the thin sections of seeds, etc., suspected of containing protein granules, must be kept for at least twelve hours. Upon removal to water, after this period, they remain substantially unchanged. The precaution must be taken not to touch with any metal the sections after they have been placed in the mercuric chloride solution. They must be removed by a camel's-hair brush.



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177. The protein matter of which protein granules consist may be wholly without definite shape, or a portion may assume somewhat the form of crystals. The latter have been called protein crystals or crystalloids, and they are generally associated, in the granules of which they form a part, with inorganic matters either amorphous or crystalline. Hence in some protein granules we have to distinguish between the inorganic contents, the

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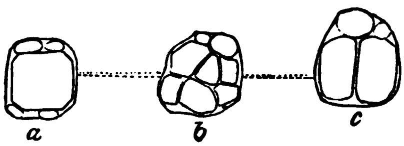
FIG. 11. Cells from cotyledons of Vicia sativa, showing protein matters in a finely divided state, intermingled with starch-granules. (Schmidt.)

FIG. 12. Protein granules from the endosperm of Ricinus communis. The specimen is in oil. $\frac{400}{1}$. (Pfeffer.)

FIG. 13. Protein granules from the endosperm of Ricinus communis. The specimen. first treated with mercuric chloride in absolute alcohol, is now in water. $\frac{400}{1}$. (Pfeffer.)

protein crystal-like bodies, and the protein basis or stroma in which all of these are held.

The protein basis sometimes, if not always, appears to consist of two substances, differing in their solubility in water, and commingled as granulose and cellulose are in starch-granules. While the protein basis is generally very soluble in water (not *per se*, but owing to the presence of potassic phosphate), the protein crystals are insoluble, or only slightly affected by it, usually becoming more or less swollen. After solution of the protein basis has taken place, a delicate membrane is left behind, and through this transparent film the protein crystals are clearly seen. The relative amounts of protein basis and protein crystals vary widely; in some cases the former appears to be wanting, the latter wholly filling the interior of the membrane. Such crystals appear in potato-tubers in the form of



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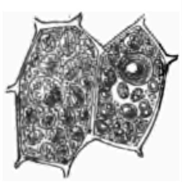
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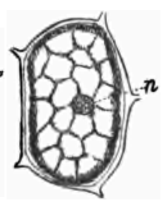

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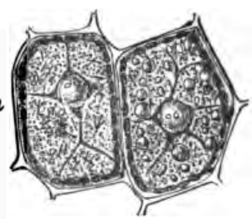
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small cubes. Protein crystals of great beauty are easily demonstrated in the endosperm of the common Brazil-nut (Bertholletia). Very instructive phenomena are presented when different sections of the seed are subjected to the following reagents; (1) osmic acid (one per cent solution); (2) hæmatoxylin

FIG. 14. Single protein granules treated as in Fig. 12. $\frac{800}{1}$. (Pfeffer.)

FIG. 15. Protein granules from Silybum marianum. In the cell on the left they have crystalline contents; in that on the right, globoids. This section was taken from the cotyledons of a dormant seed, and after treatment with mercuric chloride in alcohol was placed in water. $\frac{540}{1}$. (Pfeffer.)

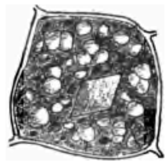
FIG. 16. The mesh of the ground mass of the cell has been cleared by dilute potassic hydrate and hydrochloric acid. n = nucleus. $\frac{540}{1}$. (Pfeffer.)

FIG. 17. Cells from the cotyledons of a germinating seed which has just ruptured the seed-coat. The protein granules have disappeared, but their contents are recognizable. $\frac{540}{1}$. (Pfeffer.)

FIG. 18. Silybum marianum. Cell from the cotyledon of a nearly ripe seed in which the formation of protein granules has just begun. $\frac{540}{1}$. (Pfeffer.)

in concentrated glycerin; (3) concentrated potassic hydrate, water being added afterwards. Permanent preparations of protein crystals can be made by first acting on the section with mercuric chloride for a day or more, washing in water, staining with eosin, and finally mounting in potassic acetate (101).

The inorganic matters associated with the protein crystals in protein granules are either (1) amorphous or globular concretions of a double phosphate of calcium and magnesium, known as *globoids*, or (2) crystalline clusters of calcic oxalate.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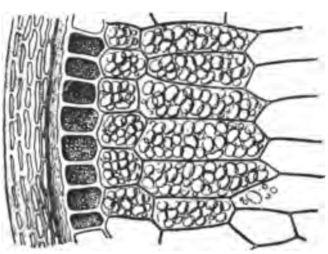
The protein granules, especially those which are most complex in their composition, are also known as *Aleurone* grains. The protein crystals are generally termed *crystalloids*.[1] For an analytical classification of protein granules in seeds, see pages 182 and 183.

178. **Starch,** the principal form in which the elaborated food of plants is held in reserve, occurs as minute spheroidal or polyhedral granules. Under a sufficiently high power, and with proper management of the mirror of the microscope, the single granules exhibit an appearance of stratification which is sometimes very distinct, but more commonly obscure; in the latter case dilute chromic acid can be used to render the stratification plainer. The layers of stratification are arranged around a point, — often very eccentrically, as in potato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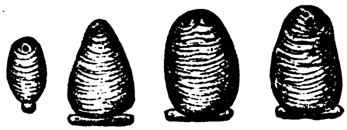
[1] The fact that protein crystals have, as a rule, less constancy in their angles than inorganic crystals, taken together with the fact of their swelling when immersed in water, has led authors to speak of them as **crystalloids** rather than as crystals. But Famintzin has recently shown that certain crystalline forms artificially produced obscure these distinctions, since they agree more closely in some of their physical characters with organic structures than with ordinary inorganic crystals (Ber. der Deutsch. bot. Gesellsch., 1884, p. 32).

FIG. 19. A cell from nutmeg lying in oil. In the ground mass are very numerous crystals of fat. Some of the granules are compound starch-granules, but others are protein granules with crystalloids. The rhombic granule has hardly any envelope. $\frac{540}{1}$. (Pfeffer.)

FIG. 20. Globoids of Vitis vinifera. $\frac{540}{1}$. (Pfeffer.)

FIG. 21. Large protein granules from Vitis vinifera. $\frac{540}{1}$. (Pfeffer.)

FIG. 22. Wheat-grain, showing cells containing starch-granules. (Schmidt)



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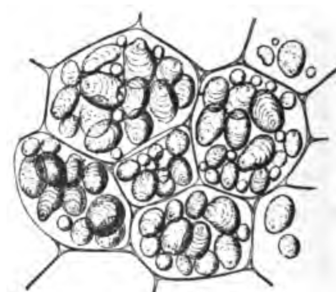
starch, or with great regularity, as in wheat. This point is known as the nucleus, or hilum. If two or more nuclei are discernible, the granule is said to be compound.

Occasionally many small single granules cohere slightly to form an aggregate which can be easily broken. According to Wiesner, there may be as many as 30,000 granules in a single aggregate of this kind.



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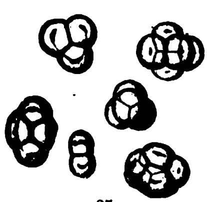
Both simple and compound granules may occur in the same cell, but some plants have only simple, and others only compound granules. Canna and Curcuma may be cited as examples of the former; Jatropha, of the latter.

Since starch occurs in every plant in all stages of development, the size of the granules must be extremely variable. Nevertheless, a statement of the more common limits may aid in their identification.



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Wiesner gives the following limits of size for some of the more common sorts of starch, first grouping them into small, medium, and large granules.

Small granules (from 0.002 to 0.015 mm.): as the simple granules of rice, oats, buckwheat; also the smaller granules of wheat, rye, barley, etc.

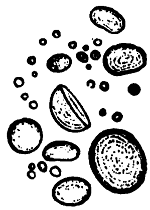
Medium granules (from 0.02 to 0.05 mm.): as the compound granules of rice and oats, the larger ones of wheat, rye, and barley, the simple granules of Indian corn, and of the common leguminous plants.

Large granules (distinguishable as granules to the naked eye): as the simple granules of Curcuma leucorrhiza, Canna edulis, potato, etc.

FIG. 23. Starch-granules from the bulb of Phajus grandifolius, showing the nucleus at the upper part and the starch generator or amylogenic body below. $\frac{540}{1}$. (Schimper.)

FIG. 24. Cells from potato-tuber, showing starch-granules. (Schmidt.)

FIG. 25. Starch-granules from sarsaparilla. (Berg and Schmidt.)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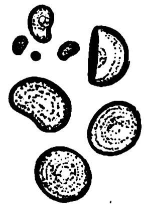
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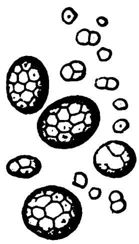
Starch is insoluble in cold water, but forms with boiling water a paste in which all traces of structure are lost. If a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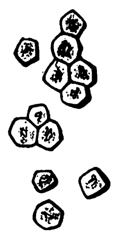
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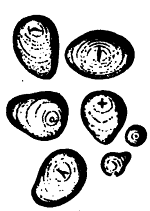
specimen of starch be gently heated with water upon a glass slide, the granules will be seen to swell at a temperature of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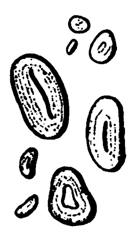
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40°–50° C., and the appearance of stratification will often become plainer. The alkalies and mineral acids generally hasten the

FIG. 26. Starch-granules of wheat.
FIG. 27. Starch-granules of Indian corn.
FIG. 28. Starch-granules of barley.
FIG. 29. Starch-granules of oats.
FIG. 30. Starch-granules of rice.
FIG. 31. Starch-granules of potato.
FIG. 32. Starch-granules of Maranta (arrow-root).
FIG. 33. Starch-granules of Bomaria (Chili arrow-root).
FIG. 34. Starch-granules of Vicia sativa, var. leucosperma. All the figures of starch are from Berg and Schmidt.

formation of starch-paste, and bring about some other changes, such as its conversion into soluble matters.

179. Starch is usually said to have the following composition, $C_6H_{10}O_5$, and these proportions are doubtless correctly stated; but it is probable that the molecular constitution is more complex than this formula would indicate.[1]

180. When starch is acted on by saliva or pepsin, it is slowly separated into two substances, one of which passes into solution, while the other remains as a skeleton, and with little change of form. This delicate framework, which remains after the soluble matter is removed, is closely related to cellulose, as shown by its behavior with reagents, and has received the name of *starch cellulose*. The substance which is removed by the action of saliva is termed *granulose*.

181. When starch is not associated with too large a proportion of protein matters, it can always be detected by the blue color which it takes with iodine in solution; but if protein substances are present in considerable amount, they may obscure the reaction by the yellowish or brown color which iodine imparts to them. Iodine does not, however, always produce a *blue* color with starch; the shade may vary towards red, forming a purple which may be almost black. Furthermore, as the transient color given by this reagent fades, it may pass through various tints of orange and yellow.

Protein matters which mask the starch reaction may be removed by careful treatment of the specimen with potassic hydrate (not too concentrated), and subsequent washing with pure water. After such treatment it sometimes happens that the starch appears as a diffused mass instead of in minute dots.

182. When starch-granules are seen in polarized light they generally exhibit two crossed lines which appear to turn as the Nicol prism is revolved. Many kinds of starch give under the polarizer characteristic figures, many of them of great beauty.

183. **Inulin,** although occurring in solution in cells, is nevertheless thrown down in characteristic forms by means of the preservative media alcohol and glycerin, and can be examined as a solid. If the root of Dahlia, Helianthus, or any of the common Compositæ which store up their food in fleshy underground parts, be subjected to the action of alcohol for a few days, thin sections will exhibit in the cells peculiar masses of a spheroidal

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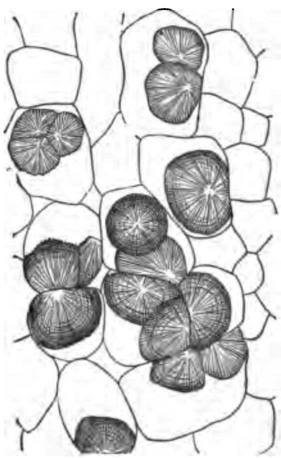
[1] W. Nägeli, however, gives the formula for starch as follows: $C_{36}H_{62}O_{31}$. Beitr. z. näheren Kenntniss der Stärkegruppe, 1874.

form which are distinctly radiating in structure. Occasionally these masses have large rifts which run across the surface of the sphere.

In composition, inulin closely resembles starch, but does not give any color with iodine. To detect it when in solution, a thin section of the plant containing it is moistened on the glass slide with absolute alcohol, when a cloudy precipitate will at once appear; in a short time (the supply of alcohol having been replenished as it evaporates) the specimen grows clearer, and small sphærocrystals of inulin are seen. If now the specimen is carefully washed with water, the smaller granules disappear and the well-defined remain.



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184. **The carbohydrates dissolved in the cell-sap** may be grouped in two classes: (1) those which are isomers of cellulose (*i. e.*, have the same percentage composition, $C_6H_{10}O_5$), and (2) the sugars.

1. The isomers of cellulose are mucilage, gums, and dextrin, all of which are probably derivatives of starch. Various substances intermediate between them have been described, but the above are all that need now be taken into account. (*a*) *Mucilage*, when not plainly resulting from the breaking up of the cell-wall, is colored red by rosolic acid, and the color is not readily removed by alcohol. (*b*) *The gums*, of which cherry gum may be taken as an example, are not tinged by rosolic acid. (*c*) *Dextrin* can be detected by Trommer's test, which Sachs applies as follows: a section which is at least a few cells in thickness is placed in a porcelain capsule with a strong solution of cupric sulphate, and the liquid is heated to boiling; the specimen is then washed in water, and dipped at once in hot potassa. If the cells contain either dextrin or grape-sugar, there will immediately appear a reddish precipitate. To discriminate between dextrin and grape-sugar, it is merely necessary to keep portions of the plant to be examined in 90 or 95 per cent alcohol, which will dissolve out the sugar and leave the dextrin, if any

FIG. 35. Sphærocrystals of inulin from root of Cichory treated with alcohol. $\frac{4}{1}^{0}$. (Jacobs.)

is present. Usually all the grape-sugar is extracted in a day or two.

2. *The sugars.* Grape-sugar has been just referred to as giving the same reaction as dextrin with Trommer's test. Its formula is $C_6H_{12}O_6$. Cane-sugar, which has the formula $C_{12}H_{22}O_{11}$, gives no red precipitate with the same test, but the liquid in the cells becomes bright blue, and quickly diffuses into the potassa.[1]

185. **Crystals** are of such general occurrence in widely different orders of the higher plants, that there are perhaps none in which they may not be detected. They have been found in nearly all parts of the vegetable structure, more commonly in the interior of parenchyma cells, sometimes in specialized crystal-receptacles, occasionally in the very substance of the cell-wall. They occur either singly or in groups; either separate or barely coherent, or in various degrees of combination.

When solitary and simple they are usually octahedra or prisms, and their aggregations are combinations of these. Good octahedral crystals are afforded by the petioles of Begonia; examples of the prismatic form are found in the outer scales of onions, in orange leaves, in the inner bark of maples and apple-trees, and in most of the tissues of Iris and its allies.

When the prisms are very long and slender their angles and faces are seldom well defined.[2] Indeed, the most attenuated forms are usually terete, or slightly flattened, and taper gradually to a point at both ends. To these De Candolle long ago gave the name *Raphides*, — that is, needles.[3] These are generally massed in a compact bundle, like a wheat-sheaf, occupying a large part of the interior of the containing cell.

Raphides are by no means of such general occurrence as are ordinary crystals, but (as Gulliver has pointed out) are seemingly restricted to certain orders.[4] They are universal in Araceæ and Onagraceæ. In the common Arums and Callas, raphides-bearing cells may readily be found in the parenchyma

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[1] Pringsheim's Jahrb., iii. p. 187. In the Sitzungsber. d. k. Akad. Wien, for 1859, Sachs has given colored figures illustrative of these reactions.

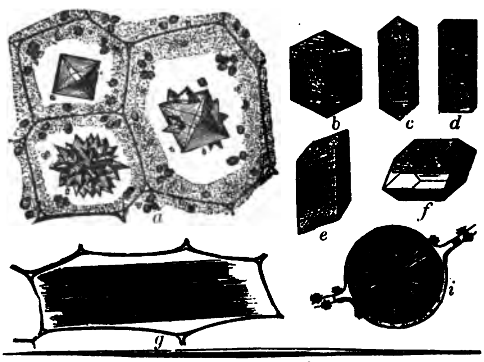
[2] When the longer prisms are clearly defined, they are referable to the monoclinic system. Measurements of angles are given by Holzner, in Flora, 1864, p. 292. A paper by Bailey (Am. Journ. of Sc. and Arts, vol. xlviii., 1845, p. 17) also contains determinations.

[3] Organographie, 1827, p. 125.

[4] Gulliver has examined representative plants of all the more important orders of the British Flora, with respect to the occurrence of diagnostic crystals (Annals and Magazine of Natural History, 1863 to 1867).

of the leaves, and detached entire; on becoming turgid when wetted, they will usually discharge their raphides one by one from one or both ends of the cell until the bundle is almost exhausted.[1]

186. When the ordinary octahedral or prismatic crystals are aggregated or combined, they generally compose a spherical mass. Such aggregations are of two principal types: (1) those made up of many small crystals irregularly grouped, and usually presenting sharp points over the surface, as in Fig. 36 *a;* (2) those with a distinctly radiated structure (Fig. 36 *i*). Good examples of the former are abundant in the foliage of Chenopodiaceæ and the stems of Cactaceæ. Clusters belonging to the latter, or stellate, type are not uncommon in Malvaceæ. Both forms have been termed *Sphæraphides*[2] and *Sphere-crystals.* The term *cystolith*, sometimes improperly applied to them, should be wholly restricted to the peculiar bodies described on page 40.



187. Owing to the mechanical difficulty of isolating plant-

[1] Turpin (Annales des Sc. nat., sér. 2, tome v., 1836) described the raphides-bearing cells of Caladium, in which this discharge takes place, under the name of *biforines.*

[2] "They are most irregularly scattered through the tissues of the plant. . . . I have never failed to find them in a single species of the order Caryophyllaceæ, Geraniaceæ, Lythraceæ, Saxifragaceæ, and Urticaceæ, and believe that few if any orders could be named in which sphæraphides do not exist as part and parcel of the healthy and growing structure of the plant" (Gulliver, in Annals and Magazine of Natural History, vol. xii., 1863, p. 227).

FIG. 36. The more important forms of crystals of calcic oxalate: *a*, three cells from the petiole of Begonia manicata; *b*, from the leaf of Tradescantia discolor; *c* and *d*, from the leaf of Allium Cepa; *e*, from the inner bark of Æsculus Hippocastanum; *f*, from the leaf of Cycas revoluta; *g*, a cell containing raphides, from the frond of Lemna trisulca; *h*, a single crystal from the same, more highly magnified; *i*, sphæro-crystal from Phallus caninus. (Kny.)

crystals for examination, their chemical composition has not yet been determined with certainty in all cases. That a protoplasmic film usually envelops both solitary and aggregated crystals, can be shown by the method pointed out by Payen;[1] namely, by dissolving the crystal slowly in very dilute nitric acid, and testing with iodine, when the film will become yellowish-brown. It has also been made out beyond question that some crystals have a considerable admixture of cellulosic matter, and that a few others are covered by a membrane of cellulose.[2] But these two substances do not obscure the chemical reactions in ordinary cases, by which it has been shown that the larger number of crystals consist of calcic oxalate, after which, in frequency of occurrence, comes the carbonate of the same metal. These two salts can be easily distinguished from each other by the following simple tests: —

Reagent.	Calcic Oxalate.	Calcic Carbonate.
Acetic acid.	No effect.	Dissolves with effervescence.
Hydrochloric acid.	Dissolves without effervescence.	Dissolves with effervescence.

Since these two salts may occur in the same specimen, it is best to use acetic acid first; by this agent all traces of the carbonate are removed, and hydrochloric acid can then be applied in order to detect the presence of oxalates. Sanio[3] and Holzner have shown conclusively that many crystals which have been supposed to be calcic carbonate consist merely of the oxalate.

Crystals of calcic sulphate have been reported as occurring in certain Musaceæ,[4] in the bark of the willow, in the roots of aconite, bryony, and rhubarb; and also in the root of a young bean.[5] Calcic phosphate is said to have been detected in the

[1] Payen : Mém. des savants étrangers, ix., 1846, p. 91.

[2] Rosanoff (Bot. Zeit., 1865, 1867), Crystals in pith of Ricinus and Kerria. Pfitzer (Flora, 1872), crystals in the leaves of orange and the bark of many trees.

Hilgers has investigated the occurrence of crystals at different periods of growth of different organs. From his results it appears, (1) that in the very youngest parts no crystals are to be found; (2) they appear, however, very early in most parts, and (3) speedily attain their maximum size, after which they undergo no change (Pringsheim's Jahrb., vi., 1867, p. 285).

[3] Sanio : Monatsber. Berliner Akad., 1857.

[4] Van Tieghem : Traité de Botanique, p. 526.

[5] Sitzungsberichte der Wiener Akad., xxxvii., 1859, p. 106.

wood of Tectona grandis (Indian Teak).[1] Holzner[2] uses the following reaction to detect calcic sulphate: a solution of baric chloride (not too concentrated) is brought into contact with the crystal under examination; calcic sulphate soon becomes covered with a whitish deposit of baric sulphate. This test failed to show the presence of calcic sulphate in the plant-crystals hitherto referred to this salt; they all gave, however, the reaction for the oxalate.

188. Crystals closely resembling in most respects those which are found in cells can be produced by Vesque's method.[3] Three test-tubes are placed side by side: in the first is a moderately strong solution of calcic chloride; in the middle one, a five per cent solution of sugar; and in the third, a solution of potassic oxalate. From the liquid in the first to that in the second a short strip of filtering-paper runs, and a similar strip passes from the second to the third test-tube; and thus the liquids in the three tubes are brought into indirect contact. Crystals will be formed in the middle tube, their character depending upon the nature of the liquid there. In a solution of sugar, raphides are produced; in pure water, prisms of small size, but with sharply defined faces and angles.

189. According to Souchay and Lenssen,[4] monoclinic ("Clinorhombic") crystals of calcic oxalate containing two equivalents of water are produced upon quick precipitation, while by very slow action right octahedra with six equivalents of water are formed.

A few works of reference are the following: —

MOHL. Principles of the Anatomy and Physiology of the Vegetable Cell. Translated by Henfrey (London, 1852). An octavo of 158 pages. This is an excellent translation of a classical work.

HOFMEISTER. Die Lehre von der Pflanzenzelle (Leipzig, 1867). An octavo of 397 pages. The volume treats very fully of the physical properties of protoplasm.

EBERMAYER. Physiologische Chemie der Pflanzen (Berlin, 1882). This is the first volume of an expensive work which deals with the relations of plants to soil and climate.

HUSEMANN und HILGER. Die Pflanzenstoffe (Berlin, 1882). Two large volumes. It has very extensive references to the literature of the subject, and most of its abstracts are excellent.

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[1] Ples: Naturkundig Tijdschrift voor Nedrlandsch-Indië, 1858, p. 345. Quoted from Holzner.

[2] Flora, 1864, p. 283. This communication contains a good abstract of the literature of plant-crystals up to 1862.

[3] Ann. des Sc. nat., sér. 5, tome xix., 1874, p. 300.

[4] Annalen der Chemie und Pharmacie, c., 1856, p. 311.

CHAPTER II.

CELLS IN THEIR MODIFICATIONS AND KINDS, AND THE TISSUES THEY COMPOSE.

190. WHILE cryptogamous plants of the lower grade may consist of single cells, or of a series or stratum of simple and undifferentiated cells, phænogamous plants, although equally simple and homogeneous at the initiation of each individual, develop into a more complex organization, at an early period differentiate some of their cells into peculiar kinds, multiply the kinds into tissues or fabric, and of these build up the organs and parts which are familiar in ordinary vegetation.

191. The microscropical study of the parts even of a single herb or tree, and much more that of a variety of plants, reveals numerous forms or kinds of cells, and also (as might be expected from their common origin) brings to view series of gradations between the kinds, sometimes even between those which are, upon the whole, widely differentiated from each other. While, therefore, a general classification of the cells of any ordinary plant into kinds is easy, any classification which shall satisfactorily exhibit our present knowledge of the histological elements, and discriminate their varieties, is very difficult, if not at this time practically impossible. At least, it must be said that the most recent classifications are based upon considerations of a character too recondite and special to be mastered at the beginning by an ordinary student.

192. The most general and obvious division of the histological components of a stem, root, or leaf would be into, (1) fundamental or typical cells, and (2) transformed cells. The first are those in which the normal cellular character persists without profound, if any, alteration or disguise; as in the pulp of leaves, the pith of stems, and in a portion of the bark. The second are those which assume or affect lengthened or fibrous forms and a longitudinal development (at least in all axes, and commonly in leaves and other expanded organs), and, combined into threads, fascicles, bundles, or more massive structures, constitute the framework, which imparts solidity and strength throughout. Some

of these cells are so long in proportion to their breadth, and of such diminished calibre, that they have naturally been called fibres, although all gradations between them and typical cells may be demonstrated. All these cells are interchangeably called woody fibres or wood-cells, and one kind of them takes the name of bast-cells.

193. Others are of larger calibre, are peculiarly marked by thickenings on certain lines or in certain patterns, incline to be developed end to end in a chain or row, and to become confluent at the junctions, so as to form conduits of considerable length; these are called vessels, or ducts. Vessels and fibres are associated in the plant; almost every separate thread of framework consists of both, and so is called a fibro-vascular bundle or fascicle. Moreover, the known gradations between the two are such as to render a complete distinction between them nearly impracticable; so that they form the fibro-vascular, or, when a single word is used, the vascular system. To this system, also, pertain specially differentiated cells, such as cribrose-cells, in the bark, etc.

194. All these are developed in or among the fundamental or untransformed cells, and originate from the differentiation of some of them.

195. The fundamental or typical cells may therefore be said to constitute the fundamental system; which may also be conveniently called the cellular system, in contradistinction to the vascular.

196. In an ordinary leaf it forms all but the framework of ribs and veins; in the stem of a dicotyledon, the outer bark, the pith, and the rays which traverse the wood; in that of a monocotyledon, which generally has a looser texture than the last, it is the common mass through which the definite bundles of the vascular system are distributed. Of the fundamental system, the most typical or unmodified cells are such as the chlorophyll-bearing cells of leaves and of the green bark of stems, as well as those with uncolored contents forming the pith, etc. Borrowing a word from the old anatomists, the early investigators of vegetable structure called tissues composed of such cells *Parenchyma*, perhaps taking the idea of the name from leaves in which the veins are distributed through the softer parts as blood-vessels through the parenchyma of the glands.

197. Parenchyma, therefore, is the name of cellular tissue in contradistinction to fibro-vascular tissue. In its primary sense, only comparatively soft and thin-walled cellular tissue

took this name, and this is indeed typical parenchyma; but the name rightly includes, as species or varieties, thicker-walled and even solidified tissues composed of cells similar in other respects to the type, as those in the hard endosperm of seeds.

198. A counterpart name, ***Prosenchyma***, was employed to designate tissues formed of elongated cells, such especially as wood-cells and bast-cells. These being usually thick-walled, and those of typical parenchyma thin-walled, this character was brought into the definition; that is, cells of prosenchyma were said to be thick-walled as well as long and narrow, those of parenchyma thin-walled as well as isodiametric. But this distinction does not hold out well. All fibro-vascular tissues are thin-walled at first, and some remain so; while portions of pure parenchyma may become thick-walled, firm and hard, or take on every intermediate condition. So that prosenchyma may be best held to denote tissue of the fibro-vascular system, and typically that formed of wood-cells.[1]

199. An explanation of the mode of production, multiplication, and transformation of cells is deferred to a later stage. Suffice it here to advert to the fact that every phænogamous plant, originating in the seed, begins as an isolated cell, which develops into a globular cluster of parenchyma cells, and grows into the embryo or rudimentary plantlet, taking on the shape and degree of development characteristic of its kind. In embryos which are considerably developed in the seed, the axis and beginnings of the leaves are already outlined or rudimentarily indicated there; in others the indication takes place in the early stages of germination.

200. From this if not from an earlier period development is no longer homogeneous. A superficial layer of the common parenchyma becomes distinguishable as the epidermis; while in an inner zone, or at special points, certain cells develop into ducts and wood-cells (prosenchyma), and thus are initially delineated the outlines of the systems or regions which are to characterize the whole growth; namely, — taking a dicotyledonous embryo for the type, — an epidermal layer, a cortical layer, a fibro-vascular zone, and a medullary portion. As stem and root develop, these primordial tissues complete themselves and have only to go on growing, each after its kind; but at the developing points (apex of the stem and of the root), as also in special portions or

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1 "Zu dem Prosenchym im weitern Sinne können wir auch die Gefässe zählen" (Nägeli: Beiträge, i. p. 2).

zones, initial differentiation continues. Here the nascent tissue, consisting of parenchyma cells, multiplying by successive divisions, and also the nascent prosenchyma as it forms and while still capable of further division, has been named *Meristem.*

201. Meristem, therefore, is not a kind of tissue, but the nascent state or early condition of any tissue. It is developing parenchyma, either multiplying as such, or differentiating into elongated forms, as for instance, in cambium.

Leaving the processes of cell-development to be considered under the head of "Growth," and the disposition of cells and tissues in the fabric to be described under the several organs (root, stem, leaf, etc.) which they compose, the kinds of cells are here to be indicated, without particular reference to their arrangement in the plant. In all classifications of objects which are understood to have been developed from one type, intermediate forms of almost every gradation are to be expected. It is specially so with plant-cells; and of them it should be said, once for all, that the kinds which have received distinct names, with or without sufficient reason, are only types, or leading modifications, — some of a very marked, some of a quite subordinate character.[1]

202. Plant-cells are to be described in this chapter under the following classification: —

I. Cells of the fundamental system, or parenchyma cells, — permanent typical cells.
   1. Parenchyma cells, strictly so called, including as modifications collenchyma cells and sclerotic parenchyma cells, or grit-cells, such as the lignified cells of seed-coats and drupes, etc.
   2. Epidermal cells, and their modifications; *e. g.*, Trichomes.
   3. Cork-cells, forming suberous parenchyma, or cork.

II. Cells and modified cells of the fibro-vascular system, — prosenchyma in the widest sense.
   1. Cells of prosenchyma proper.
      a. Typical wood-cells and woody fibres, including libriform cells (Sanio), and the secondary wood-cells (De Bary).
      b. Vasiform wood-cells, or Tracheids.

[1] Sometimes a single cell in a uniform tissue may develop unlike its neighbors as regards one or more of the following characters: form, size, nature of cell-wall or cell-contents. Such cells are termed by Sachs, idioblasts.

2. Vessels, or ducts.
   a. Dotted.
   b. Spirally marked.
   c. Annular.
   d. Reticulated.
   e. Trabecular.
3. Bast-cells, Bast-fibres, or Liber-fibres.

III. Sieve-cells, or Cribrose-cells.

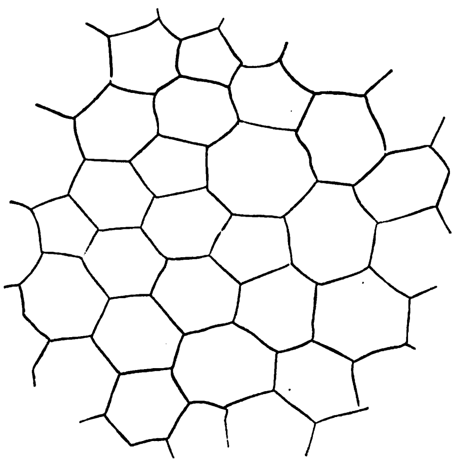
IV. Latex-cells.

Intercellular spaces and canals are neither cells nor tissues, but they require consideration in connection with them.

I. Cells of the Fundamental System,—Parenchyma in the widest sense, including Modifications for Protective Surfaces.

PARENCHYMA.

203. This term is applied at present to all typical cellular tissue except that which belongs to the epidermal system. It therefore constitutes the mass which surrounds fibro-vascular bundles, forming pith, medullary rays, the pulp of leaves and fruits, etc. It occurs in nearly all parts of all plants.



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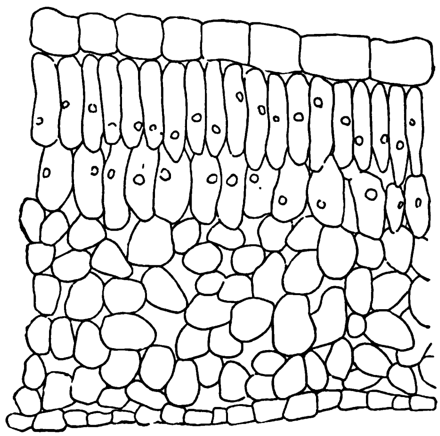
The elements of parenchyma are simple cells more or less separable from each other, in some cases by slight pressure, and in others by the cautious use of a macerating solution. The cells vary greatly in form, but usually are polyhedral or spheroidal. Extended classifications of the cells themselves, based upon form, have been made, but they are of no utility and of small historical interest. Yet three principal shapes may well be distinguished; namely, short or isodiametric, elongated, and flattened.

FIG. 37. Parenchyma from stem of Marrubium. $\frac{140}{1}$. (Jacobs.)

204. In the youngest state of organs short parenchyma cells form the whole mass; here they are relatively small, filled with protoplasm, and have no intercellular spaces. Later they are changed in shape and size, may have conspicuous intercellular spaces, and the protoplasm may be replaced, at least in part, by other matters.



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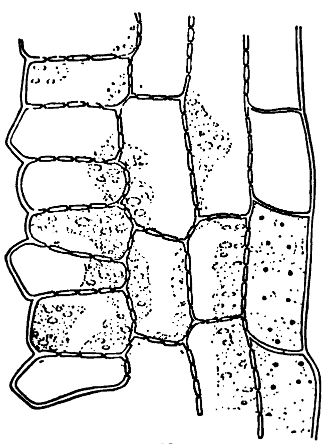
205. If the cells are loosely aggregated and have conspicuous intercellular spaces, the tissue is called *spongy parenchyma.* The cells in such cases are apt to be more or less branched, and in some plants assume regular stellate forms.

206. Elongated parenchyma cells are generally more compactly combined than the short ones. They are well seen in the upper part of most leaves, where they have received the significant name *palisade-cells.*



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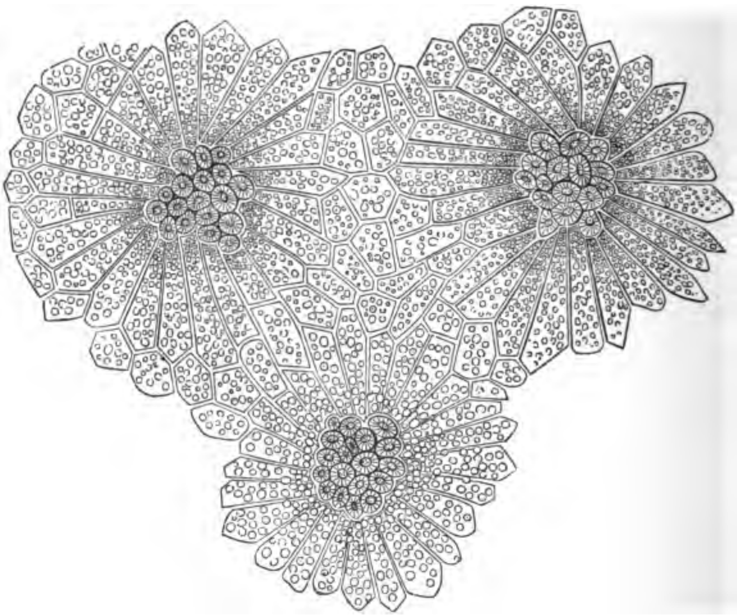
207. Flattened parenchyma cells are the common form in the vertical plates (medullary rays) which radiate from the pith to the bark in woody plants.

208. The walls of typical parenchyma cells are thin, and may be variously marked with pits, especially at the points of contact with other cells. Thickening threads forming reticulations and spirals are not uncommon; the latter occur in the aerial roots of Orchidaceæ. A crumpling or folding-in of the wall is seen in some of the cells of pine leaves.

FIG. 38. Forms of parenchyma in leaf of Pyrus communis. (Jacobs.)
FIG. 39. From pith of Sambucus nigra, showing pitted walls. (Gris.)

209. Thin-walled parenchyma cells play an important part in assimilating and storing, and special names are given to cells which have these offices, such as chlorophyll parenchyma, starch parenchyma, etc. In the tissues of most succulents, and in the leaves of a few plants, some of the parenchyma cells are filled with clear sap and more or less mucilaginous matter, and constitute the so-called water tissue.

210. The walls of typical parenchyma cells consist of ordinary



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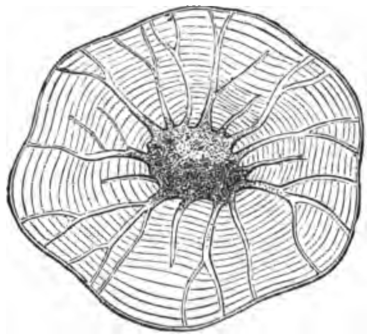
cellulose; but even slight deviations from the type furnish good illustrations of lignified and of cutinized membranes.

211. Lignification may increase the thickness of the cell-wall, greatly reducing the cell-cavity, or it may merely harden the membrane without much thickening. The parenchyma cells found associated with other elements in woody tissues have walls of the latter character; the grit-cells in pears and many other fruits show good examples of the former. Such hardened cells are called sclerotic parenchyma cells.

FIG. 40. Sclerotic parenchyma cells from fruit of the pear. (Weiss.)

In many cases it can be shown that canals run through these thickened walls, as shown in Fig. 41.[1]



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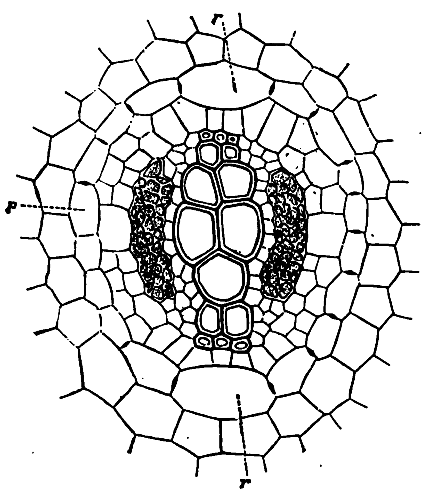
212. Certain modified parenchyma cells are often united to form sheaths around fibro-vascular bundles. These cells are prismatic, and in close apposition. Their walls are thin, except at their faces of mutual contact, where they are conspicuously thickened, and often plicate, and nearly all parts of the membrane are more or less cutinized.



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213. These cells constitute the *endodermis*. They generally contain a large amount of starch.

214. Parenchyma cells may undergo the mucilaginous modification (see 147), as in the conductive tissue of the style of many flowers and the albumen of many seeds. This change is common also in the lower plants.

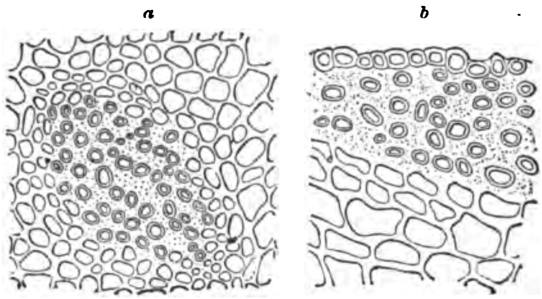
215. An appearance closely resembling in some points that produced by the mucilaginous modification is pre-

[1] A second kind of sclerotic parenchyma sometimes accompanies the longer sclerotic cells in a few ferns and some monocotyledons. Its cells appear as if segments of a jointed fibre, somewhat flattened on the side next the long cells, and decidedly convex on the other. Such flattened cells are unequally thickened on the two sides, and the walls are somewhat silicified. But the most striking feature in many cases is the deposition within the cavity of the cell of a mass of silicic acid ; this is well seen in the hard cells which accompany the fibro-vascular threads in the leaves of some palms.

FIG. 41. A sclerotic cell from the nutshell of Juglans regia. (Reinke.)

FIG. 42. Section through the central cylinder of a binary root of a vascular cryptogam (Cyathea medullaris). *p*, *r*, *r* = *endodermis*. (Van Tieghem)

sented by the parenchyma cells just under the epidermis, or outer layers of cells, in many plants. The cell-wall is thickened



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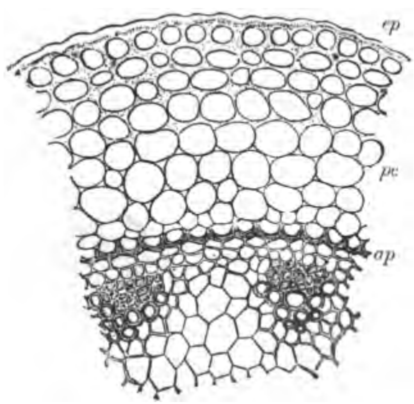
very considerably at the angles, and upon the application of dilute acids swells greatly, but without becoming clearly mucilaginous. When moist, such cells have a bluish-white color and a marked lustre. They are known as



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216. **Collenchyma cells.** They are generally somewhat elongated, and so united as to form threads which possess great strength, and are believed to serve an important mechanical office in the plant. Good examples of these are afforded by the stems of many Umbelliferæ.

EPIDERMIS.

217. This is the outermost layer of cells covering the surface of the plant. In some of the higher plants it persists with little change throughout the life of the organism; in others it is

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FIG. 43. Parenchyma with walls which have undergone the gelatinous modification: *a*, from the centre of the style of Salvia scabiosæfolia; *b*, from the stigma of Gesneria elongata. (Capus.)

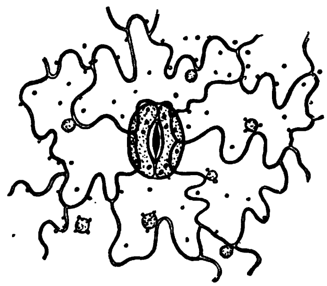
FIG. 44. Transverse section of root-stock of Smilacina bifolia, showing collenchyma cells just under the epidermis, *ep*. Note also the ordinary parenchyma at *pc*, and the endodermis at *ap*. (Van Tieghem.)

sooner or later thrown off, and replaced by a subjacent protective tissue, — cork.

218. Except at peculiar openings (stomata, etc.), the epidermal cells are in close apposition. Upon their exposed surface they are cutinized, and thus a continuous hyaline film is formed, known as the *Cuticle.*[1]

219. Sometimes the epidermis may be torn off without much disturbing the underlying tissues.

220. Besides the cells which compose the proper tissue of the epidermis, there are certain appendages or accessory structures, mainly hairs or analogous productions (together called trichomes), and peculiar cells which constitute the stomata.



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221. **Epidermal cells proper** are in uninterrupted contact. They are usually of a tabular or prismatic form. The lines which mark their outlines as viewed from above are sometimes straight, but oftener sinuous, at least on the longer sides of the cell, which here as elsewhere correspond with the direction of growth. Near stomata and trichomes the cells frequently assume very irregular forms.

222. Their upper or free surface is generally slightly convex, and often has minute outgrowths, for instance, in velvety petals; when these are larger and longer, they constitute the simplest form of plant hairs.

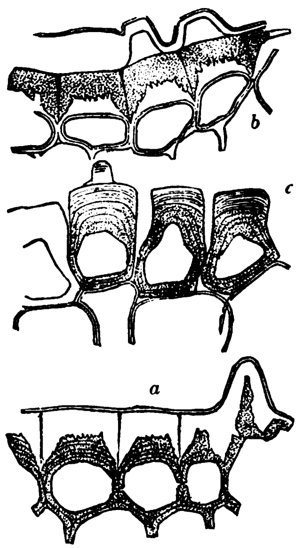
223. Delicate epidermis possesses thin walls; but in a large number of fleshy and tough plants the walls have considerable thickening, yet not always on the same part. Thus in the leaves of Cycads the upper wall is the thicker; in many Bromeliaceæ, the lower and side walls. In a few cases the cell-cavity is nearly filled by the thickening material. Stratification, striation, and pitting of the cell-wall may also occur, great diversity existing in all these respects.

224. When the epidermis is very delicate, the demonstration of the thin film of cuticle requires great care in the employment

[1] By De Candolle the term *cuticle* was applied to the layers of epidermal cells, and not restricted to the cutinized film (Physiologie, 1832, p. 109).

Fig. 45. Stoma of Sambucus nigra surrounded by epidermis.

of the reagents. According to de Bary,[1] the cuticle merely covers the pure soft cellulose membrane of the epidermal cells when these are thin-walled; but when the walls are thicker, especially in epidermis which is long-lived, that part of the cell-wall which borders on the cuticle becomes infiltrated with cutin, and thus there arise one or more layers of modified cellulose, each of which exhibits the reactions of cutin. When such cells are treated with warm potassic hydrate (a ten per cent solution is, on the whole, strong enough), the cutin is slowly removed, and the cellulose wall remains, although with considerable loss of substance. Walls which are thus impregnated with cutin in strata form *cuticularized layers*.[2] The management of a warm solution of potassic hydrate, in order to obtain satisfactory results in the demonstration of the fine stratification, demands much care. It is advisable to apply very gradual increments of heat to the glass slide in the case of the more delicate specimens.



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225. Waxy and resinous matters are frequently associated with the cuticle. In some cases the amount of such substances is large, and assumes commercial importance. The young leaves of the wax palm (Ceroxylon andicola) are said

1 Vergleichende Anatomie, p. 80.

2 This division into apparent lamellæ can be easily demonstrated in some cases by the application of chloroiodide of zinc, which imparts a yellowish color to the thick film, except at its outer surface. Mohl explained the structure of the exposed cell-wall in Viscum album, where the film is very thick, as follows: "The epidermis cells consist here of two or three generations enclosed one within another, of which all the thickened walls on the outer side have become blended together into a membrane composing the cuticle. These layers are to be called the cuticular layers of the epidermis, to distinguish them from the mass secreted on the outside of the cells, the true

Fig. 46. Transverse section of the leaf of Aloe verrucosa: *a*, section in water, — the non-cuticularized parts of the membranes shaded; above these are the cuticular layers covered by the cuticle proper; *b*, section heated in potassic hydrate; the cuticle proper has been raised from the cuticularized layers; *c*, section boiled in potassic hydrate; cuticle proper removed, epidermal cells separated, cuticular layers distinguished by finer stratification.

to yield twenty-five pounds of wax to each tree. Bayberry wax is a more familiar example.

226. To such waxy coatings is due the glaucous appearance of the leaves and fruits of many plants. The coatings are chiefly of the following kinds (de Bary[1]) : —

1. Coherent layers or incrustations upon the epidermis. 2. Crowded vertical rods of considerable length, as, for instance, those on the internodes of Saccharum officinarum, from ten to fifteen hundredths of a millimeter in height. 3. Very short rods or rounded grains. These, on the leaves of Tropæolum, are not very near together, but on those of the cabbage, tulip, etc., are more crowded. 4. When the grains are more minute, and have the shape of needles irregularly massed together, they constitute the peculiar bloom of the leaves of Eucalyptus, Ricinus, etc.

227. Between the above kinds there are many intermediate ones, Agave Americana, for instance, furnishing forms between the two last named.

228. Epidermal cells proper have a delicate lining of protoplasm and a distinct nucleus. The cell-sap is generally colorless and transparent, allowing light to pass with very little obstruction to the layers beneath the epidermis; but in some cases it is so colored as to impart a conspicuous hue to the plant. In many water-plants there is no well-marked distinction between epidermis and the subjacent tissue, even the cells of the upper layer containing chlorophyll, but epidermal cells are mostly free from either chlorophyll or starch. Brongniart has shown that some amphibious plants have chlorophyll in the epidermal cells of the aquatic but not of the terrestrial form. That the rule is not universal is shown by Callitriche, which, according to Hegelmaier, has epidermis without chlorophyll in both forms.

229. Epidermis usually consists of only one stratum of cells, but it may be made up of two, three, or even more layers. Division of the original epidermal cells by one or more partitions parallel to the surface of the leaf gives rise to superposed cells; and thus *multiple epidermis* results, as in the upper surface of

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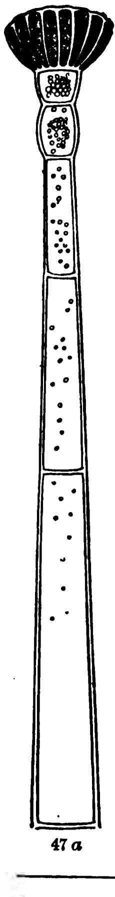
cuticle, which is soluble in caustic potash, and in most cases forms but a very thin coating over the epidermal cells" (Veg. Cell, Henfrey's trans., p. 35). Good examples for study of the different kinds of cuticular infiltrations are afforded by the following, — leaves of Dianthus caryophyllus, Galanthus nivalis, Ilex, Pinus, Hoya, Sassafras, and Taxus, and twigs of Viscum and of Oleander.

[1] Botanische Zeitung, 1871.

the leaves of many species of Peperomia, Ficus, and Begonia. Multiple epidermis is not always of even thickness throughout; sometimes a portion may be only one or two cells thick, while adjacent portions are composed of many layers. Such differences are generally associated with the occurrence of stomata, hairs, etc. The subjacent cells in some forms of multiple epidermis are smaller than those above them, and in these cases the arrangement of the cells in the successive layers presents striking inequalities.



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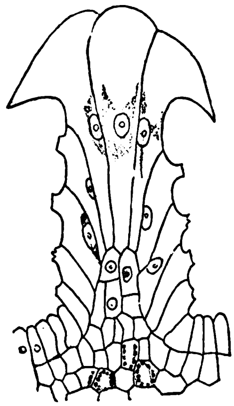
47 b



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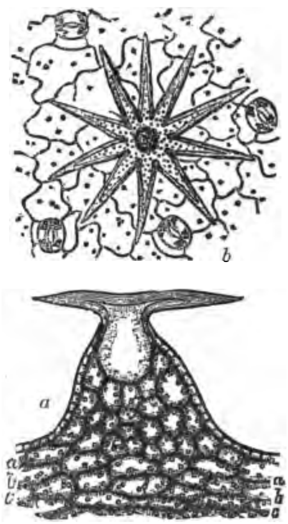
230. **Trichomes.** Under this term are included the multifarious forms of hairs, scales, bristles, and prickles. *Hairs* are sometimes of diverse forms on the same plant, and even on the same part, but sometimes so peculiar and uniform throughout large genera, or even orders, that they aid in their identification; as, for instance, in Malpighiaceæ, Loasaceæ, and Elæagnaceæ.

231. Simple hairs, whether branched or unbranched, are formed by the prolongation of a single epidermal cell, either slight, forming a mere papilla, or to a great length, as in the so-called fibres of cotton. Simple hairs are abundant upon the rootlets of most plants at a little distance behind the advancing tip, where they play an important part.

232. Compound hairs are of all degrees of complexity. They may start from a single cell, or from a group of cells, and may have the derivative cells arranged in many ways. The cells at or near the

FIG. 47 *a*. Upper portion of a glandular hair of Martynia proboscidea. $\frac{150}{1}$. (Martinet.)
FIG. 47 *b*. View from above, of the upper portion of the same. $\frac{300}{1}$. (Martinet.)
FIG. 48. Cynoglossum officinale. Longitudinal section through a young angular bristle at the beginning of the thickening. $\frac{240}{1}$. (Strasburger.)

foot of the hair may differ somewhat in shape, size, and arrangement from the other epidermal cells. They may form an eminence upon which the foot rests, or they may be somewhat sunken so that the body of the hair hardly reaches the general surface of the epidermis; but usually the hair projects for a considerable distance above the border of the depression.



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Both simple and compound hairs may be variously curved and branched, giving rise to stellate and many other forms.

233. *Scales* are trichomes which are mostly compound, and consist of discs borne by their edges or centres, either with or without a short foot or stalk. If the disc is composed of radiating cells, the scale becomes stellate, a form which resembles or passes into the stellate and tufted hairs common in Malvaceæ, etc. Well-marked stellate scales are met with in Oleaceæ and Elæagnaceæ.

234. *Bristles, prickles and epidermal spines* are firmer or stouter outgrowths. When such outgrowths are truly epidermal, they come off with the epidermis.

Hairs, scales, and prickles differ very greatly as to their persistence, some being exceedingly short-lived, as, for instance, the hairs which occur on roots; while others, for instance the prickles on the rose, last for long periods.

235. In certain outgrowths from the edges of leaves or elsewhere the structure is complicated by the presence of a portion of the underlying framework. This is notably the case in the fringe upon the leaves of Droseraceæ. There are all degrees of variation between such trichomatous outgrowths and spinulose teeth, or lobes.

236. The consistence of the cell-wall in trichomes varies widely, from extreme tenuity to the density of a silicified wall. The more delicate hairs are transparent, so that the contents

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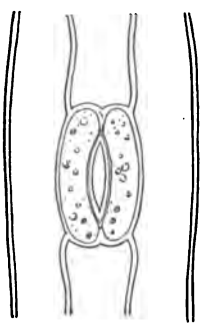
FIG. 49. Branching unicellular hairs: *a*, from Humulus (the hop); *b*, stellate hair of Deutzia. (Van Tieghem.)

can be plainly seen, thus affording opportunity for examining the movements of protoplasm, and for the study of the effects of reagents upon the contents of cells.

Young hairs contain much protoplasmic matter; at a later stage they have a large proportion of cell-sap; still later many are filled only with air.

237. At first the epidermis is always completely continuous, the cells being in close contact with each other; but soon there appear, especially in leaves, guarded openings through which the interior of the plant is brought into communication with the surrounding atmosphere. These apertures are of two principal kinds, the most important and widely distributed being

238. **Stomata.** These are combinations of epidermal cells of a peculiar character, between which a narrow slit extends directly through the epidermis to an intercellular space below. The cells bordering the slit are well termed guardian cells, on account of their opening and closing under certain circumstances. The neighboring epidermal cells are frequently arranged in a definite order; and the position of the stoma has in many cases a plain relation to the underlying framework.



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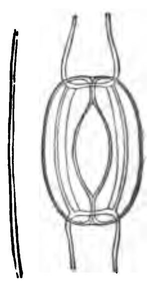

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Stomata belong especially to green organs exposed to the air; but they have been detected on all superficial parts of the plant, with the exception of roots.[1]

239. Viewed from above, stomata appear generally as elliptical bodies through which runs a narrow slit in the direction of the longer diameter. Each guardian cell is therefore half the ellipse. The cleft varies in width according to certain external condi-

[1] The following cases are cited by de Bary (Vergl. Anat., p. 49): On rhizomata and tubers (young potatoes), on the perianth, the anther (in Lilium bulbiferum), on the pistil, on the seed-coat (Canna). Plants destitute of chlorophyll may also be destitute of stomata, as in Monotropa Hypopitys; or have them only on the pistil, as in Lathræa.

FIG. 50. Adult stoma of Hyacinthus orientalis, seen from above. (Strasburger.)
FIG. 51. The same, seen from below.

tions hereafter to be described, the stoma being in fact a delicately balanced valve. A vertical section shows that the outer part of the opening is wider than the narrow passage farther down, and that the space below this widens somewhat towards the intercellular cavity.[1]

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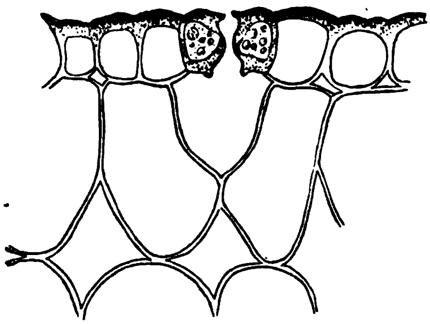
[1] The following table, compiled from figures given by Weiss, gives the number of stomata on the upper and under sides of the leaves of various plants for the most part readily procurable by students. To show the wide differences in size, the longer and shorter diameters have been added, and, finally, the fraction of a square millimeter covered by a single stoma.

Name of plant.	Number in sq. mm.		Length.	Breadth.	The space in a sq. mm. covered by a stoma.	
	Upper side.	Under side.			Upper side.	Under side.
Abies balsamea	0	228	0.047	0.031	0	0.2660
Abies nigra	31	82	0.042	0.027	0.0276	0.0781
Acer Pseudoplatanus, L. . .	0	400	0.024	0.017	0	0.1280
Amarantus caudatus, L. . .	171	193	0.012 / 0.026	0.012 / 0.017	0.0195	0.0672
Anemone nemorosa, L. . . .	0	67	0.045	0.040	0	0.0947
Asclepias incarnata, L. . . .	67	191	0.026	0.018	0.0247	0.0702
Avena sativa, L.	48	27	0.054 / 0.060	0.035 / 0.050	0.0706	0.0554
Berberis vulgaris, L.	0	229	0.033	0.022	0	0.1305
Betula alba, L.	0	237	0.029	0.018	0	0.0972
Brassica oleracea, L.	219	301			0.1137	
Buxus sempervirens	0	208	0.032	0.031	0	0.0942
Caltha palustris, L.	—	43	0.042	0.034	0	0.0482
Euphorbia Cyparissias, L. . .	0	259	0.027	0.018	0	0.0989
Ficus elastica	0	145	0.028	0.019	0	0.1187
Galanthus nivalis, L	30	55	0.034	0.022	0.0176	0.0323
Geranium Robertianum . . .	—	297	0.045	0.032		0.3356
Helianthus annuus, L. . . .	175	325	0.034	0.023	0.1074	0.1995
Hydrangea quercifolia, Bertr.	0	330	0.020	0.019	0	0.1015
Ilex Cassine	0	212	0.029	0.025	0	0.1206
Juglans nigra, L.	0	461	0.024	0.018	0	0.1563
Lilium bulbiferum, L. . . .	0	62	0.071	0.050	0	0.1751
Maclura aurantiaca, Nutt. . .	0	251	0.022	0.016	0	0.0695
Mimosa pudica, L.	138	302	0.017 / 0.026	0.009 / 0.015	0.0164	0.0927
Morus alba, L.	0	480	0.018 / 0.029	0.008 / 0.021	0	0.0547
Nymphæa alba, L.	460	0	0.026	0.022	0.2070	
Pinus Strobus, L.	142	0	0.054	0.032	0.1945	
Pinus sylvestris, L.	50	71	0.034	0.023	0.0307	0.0436
Pisum sativum, L.	101	216	0.024	0.017	0.0323	0.0691
Pittosporum Tobira, Ait. . .	0	382	0.031	0.027	0	0.2494
Populus dilatata, Ait. . . .	55	270	0.035 / 0.033	0.024 / 0.021	0.0363	0.1471
Ribes aureum, Pursh	0	145	0.036	0.025	0	0.1025
Secale cereale, L.	—	25	0.051	0.029	0	0.0269
Sequoia gigantea (young plants)	0	82	0.053	0.033	0	0.1434
Silene inflata, Sm.	71	166	0.033	0.021	0.0386	0.0905
Solanum Dulcamara	60	263	0.021	0.014	0.0139	0.0607
Stellaria media, Sm.	128	—	0.029	0.026	0.0758	
Syringa vulgaris, L.	0	330	0.028	0.016	0	0.1162
Vinca minor, L.	0	477	0.029	0.018	0	0.1961
Vinca minor, var. variegata .	0	405	0.024	0.016	0	0.1223
Zea Mais, L.	94	158	0.037	0.029	0.0792	0.1332



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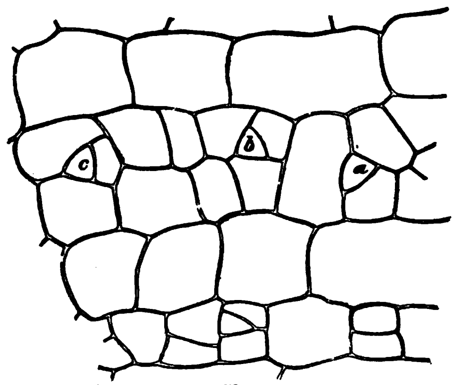
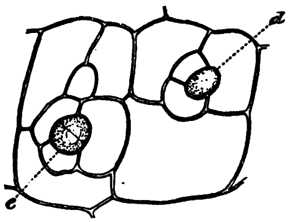
240. As appears from the following figures, the first stage in the development of an ordinary stoma is the separation of a part of an epidermal cell by means of a vertical partition, thus forming the mother-cell of the stoma. This next divides by a vertical plane which soon exhibits a narrow chink. The cells thus slightly separated at their common wall may by subsequent growth bring about changes in the relations of the neighboring cells.



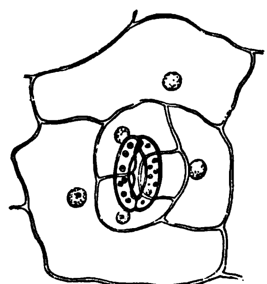
53 *a*

In Sedum, as shown by Strasburger, there are preparatory divisions in different directions, while in some monocotyledons there are simultaneous divisions in contiguous epidermal cells.

241. Stomata are not present, at least in a perfect form, in any submerged plant. In aquatics with



53 *b*

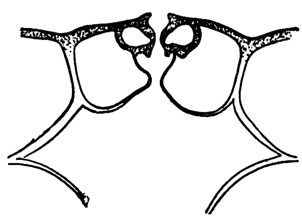


53 *c*

FIG. 52. Vertical section of stoma of Hyacinthus orientalis. (Strasburger.)

FIG. 53 *a*, *b*, *c*. Three stages in the development of the stomata of Sedum spurium. Fig. 53*c* shows the narrow slit made by the neighboring epidermal cells. (Strasburger.)

floating leaves they are confined to the upper surface of the leaf. The leaves of certain plants, as those of monocotyledons and those which take a vertical position, have them in nearly equal numbers on the two sides; but in most cases the number on the under exceeds that on the upper surface, as will be seen from the table on page 71. As regards the approximate number on leaves of average size in some of our common plants, the following figures may be of interest: —



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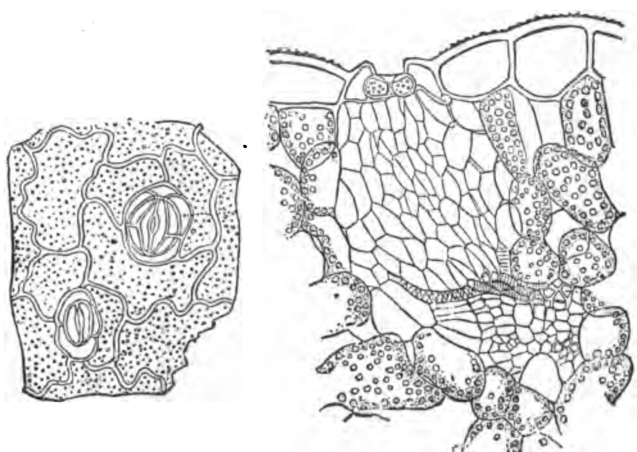
Nymphæa	7,650,000
Brassica oleracea	11,540,000
Helianthus annuus	13,000,000

242. *Water-pores.* Directly over the extremities of the fibres of the framework of many green leaves are found apertures in



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the epidermis which have no true guardian cells,[1] but which closely resemble ordinary stomata in most other respects. Owing

[1] That is, the bordering cells do not close under external influences.

FIG. 54. Vertical section of stoma of Sedum spurium. (Strasburger.)

FIG. 55. Water-pores in leaf of Rochea coccinea. The left-hand figure shows both an ordinary stoma (the lower one) and a water-pore (the upper), as seen on upper surface of leaf. The right-hand figure shows the structure displayed by a vertical section. (Van Zieghem.)

to the fact that their cavity answering to the intercellular space of a stoma is often filled with water instead of air, these have been called water-pores. At certain times liquid water passes through these pores, collecting at the opening and sometimes leaving there, upon evaporation, slight incrustations of calcic carbonate. Water-pores assume different forms and vary much in size. Good examples are afforded by many Aroideæ, by the teeth of the leaves in some species of Fuchsia, the leaf-margins in Tropæolum, etc.[1]

Small rifts of nearly the same shape can be found in certain grasses; but in these the aperture comes from a mechanical rupture,[2] and the underlying structure is very simple.[3]

CORK.

243. This protective tissue is formed beneath and replaces epidermis in the older superficial parts of plants; it also constitutes the films by which wounds are healed. Only the inner layers of cork-tissue possess cellular activity, those which lie outside of them having perished: the former contain protoplasm and are capable of cell-division; the latter contain air, and occasionally small clusters of crystals. The inner, active, and growing layers are known as cork meristem, cork cambium, or *Phellogen;* the outer, produced from this and no longer living, make up the bulk of the outer bark, and are ordinarily called cork. Although the older cork-tissues must be further described in Chapter III., under "Bark," their elements may be conveniently treated of now in connection with the cells which produce them.

244. Origin. Cork may arise from several different sources, the principal of which are the following: (1) from division of cells in the epidermis (*e. g.*, species of Pyrus, Salix, Viburnum, etc.); (2) more commonly from underlying parenchyma, in a few cases even from that which occurs in the inner bark (the bast parenchyma), as in Vitis and Spiræa; (3) from parenchyma at injured surfaces, as in the healing of wounds.

245. It is normally produced upon the stems and roots of flowering plants, especially dicotyledons. Its cells are generally

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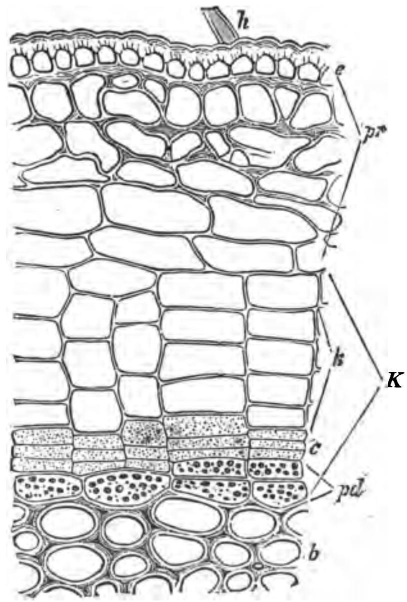
[1] For a full account of water-pores, see de Bary's Anatomie, p. 54, and Jahrb. konigl. botan. Garten, Berlin, 1883.

[2] De Bary: Anatomie, p. 57.

[3] Gardiner: Proceedings Camb. Phil. Soc., 1883.

formed by the division of the mother-cell into two tabular cells, by a partition parallel to the surface of the organ. In most cases the outer cell becomes cork, while the inner retains its power of division and in turn produces new cells. But with the first appearance of the cork-layer a change takes place in all layers lying to the outside of it: they are cut off from nutritive supplies and soon die. The continuous layers of cork are called, collectively, *Periderm*, a name restricted by Mohl to tough cork in distinction from soft cork, but now employed with a wider signification.



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246. Cork meristem gives rise to successive layers of cork-cells: if the new layers differ much from the preceding in the shape and size of their cells, an appearance of stratification naturally results. Cork meristem may, in exceptional instances, produce on its inner side permanent parenchyma, the cells of which contain chlorophyll; these green layers are called *Phelloderm*, and are observed well in the beech, willow, etc. (see Chapter III.).

247. Cork-cells are tabular, or sometimes cubical, and with few exceptions have no intercellular spaces. In the case of very flat cells which cohere more firmly laterally than in the line of the radius, the cork-tissue may be readily separated in films or sheets.

248. The walls of older cork-cells are cutinized or suberized throughout. The demonstration of cellulose in cork-cells is not possible unless the cells have been first acted on by solvents,

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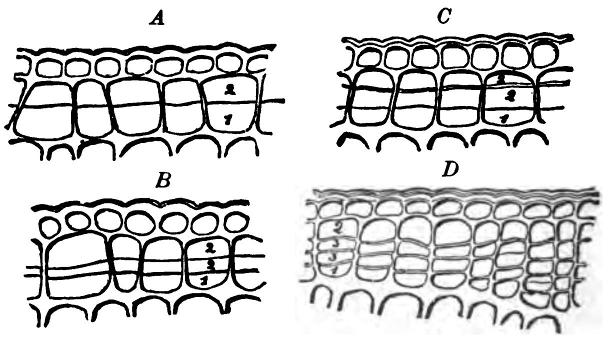
FIG. 56. Formation of cork in a branch of Ribes nigrum, one year old; part of transverse section: *h*, hair; *e*, epidermis; *pr*, cortical parenchyma, somewhat distorted; *K*, the total product of the phellogen *c*; *k*, cork-cells; *pd*, phelloderm; *b*, bast-cells. (Sachs.)

such as caustic potash, and the like. But sometimes the cell-wall seems to be completely changed into cork-substance.

249. Cork-substance behaves towards reagents in nearly all respects as cutin does (see 157).



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250. Cells which have been completely suberized can be separated from each other by the gradual action of Schulze's macerating solution.[1]

251. The color of cork-cells is not dependent upon the amount of the change of the wall into cork-substance. The walls of the cells in some species of willow are colorless, while those in other species are distinctly yellow; and yet the former have been as thoroughly changed into cork-substance as the latter.

II. Cells of the Fibro-vascular System, — Prosenchyma in the widest sense.

252. The cells and modified cells of this system constitute the framework of a plant. In a few of the higher and in many of the lower plants it is barely if at all developed, the entire structure consisting, in such cases, of a mass of parenchyma covered by epidermis. But in most plants it exists as a skeleton

[1] This fact has led to the belief that there exists in such cases an intermediate plate which differs in its character from the rest of the cell-wall; but prolonged action of the same reagent, especially with warming, causes the cells to break down and ultimately form a disorganized mass.

FIG. 57. Formation of cork and secondary cortex in Betula verrucosa. *A*, *B*, *C*, *D*, successive stages; 1, first layer of secondary cortex; 2, layer which divides in *B*, to give outside the first layer of cork (shown in *C*), and a layer, 3, within, which again divides in *D*. (Sanio.)

bringing all parts into closer relations, and strengthening the whole.

253. The cells are normally of considerable length in proportion to the transverse diameter, and are generally more or less sharply pointed (prosenchyma proper). The most important of the modified cells belonging to this system unite to form long rows in which the terminal partitions are nearly or quite obliterated, throwing the cavities into one, and thus forming a cylinder, termed a *duct*. Between proper prosenchyma cells and ducts there are numerous connecting forms which render impossible any attempt at classifying them exactly.[1]

Associated with these cells, but differing in some important particulars, are cribrose and latex cells, which for convenience are here to receive separate treatment.

254. Before developing the provisional classification given on page 59, attention must first be directed to the peculiar transitional forms constantly met with, which belong as much to parenchyma as to prosenchyma, but are more conveniently examined in connection with the associated wood-elements.

Chief among these intermediate forms must be mentioned those of which Fig. 58, No. 9, may be taken as a representative. Here the whole structural element is isolated as an elongated combination of three cells, one of which has flattened ends, while the other two, attached to these ends, have their free extremities pointed. In spite of their form, such cells are usually described as wood-parenchyma cells. When their walls are thicker, they are not easily distinguishable from septate libriform cells (see 263).

255. The forms shown in Fig. 59, No. 19, are common in the wood of many plants, notably the oaks. They are relatively small, have rather blunt extremities and thin walls. They occur with these characters especially in the autumnal wood of the oaks (see 395), while in the spring wood they are apt to

[1] For the satisfactory study of the relations of the elements of prosenchyma, very thin sections are necessary; but for the examination of the elements themselves, recourse to some process of maceration, by which they can be isolated, is always desirable. In general, there is nothing preferable to Schulze's solution in any strength adapted to the special case; it must be remembered that the slow action of a dilute solution gives better results than the more rapid action of a concentrated one. If the section to be examined is first subjected to the action of the macerating solution of proper strength and then thoroughly washed, it can be dissected at pleasure under a high power of a simple lens. This method is always to be preferred to the ordinary one of disintegrating the whole specimen and obtaining a confused mass of separated cells.

pass over into the variety shown in Fig. 59, No. 18. The latter are known as "conjugate cells."

PROSENCHYMA PROPER.

256. **Typical wood-cells.** These are best illustrated by elongated, often pointed cells, of which good examples are found in the cambium layer (that is, the layer of merismatic or formative

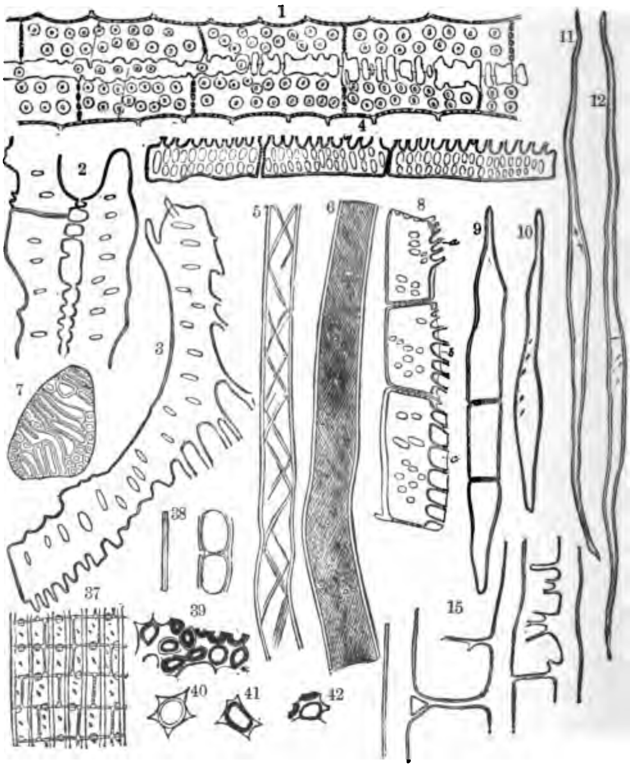

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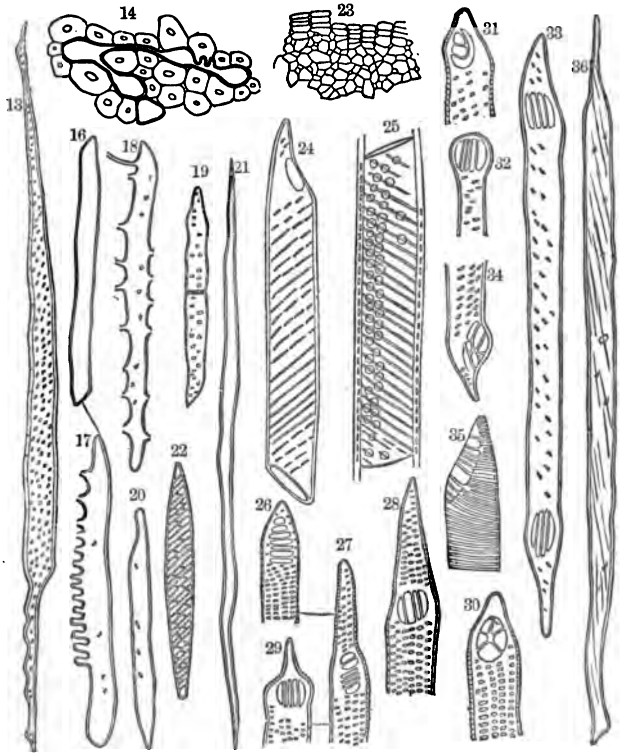
FIG. 58. Drawings of wood-elements. 1-7. Avicennia sp. 1. Wood-parenchyma cells united with each other; tangential section. 2, 3, 4. Conjugate wood-parenchyma cells isolated by Schulze's solution. 5, 6. Portions of spirally striated libriform fibres isolated by Schulze's solution. 7. The septum of a duct. 8-12. Tectona grandis; the elements separated by maceration. 8. Conjugate wood-parenchyma cells. 9. Ordinary wood-parenchyma fibre. 10. Substitute fibre. 11. Simple libriform fibre. 12. Septate libriform fibre. 15. Porlieria hygrometrica; conjugate substitute fibres seen in radial section. The wood-cells are omitted in order not to confuse the diagram. 37. Radial section through the wood of Jatropha Manihot. 38. Tangential section through a libriform fibre and two cells from a medullary ray of the same plant. 39-42. Bast-cells of Cytisus Laburnum. 39. Cross-section through a part of a young bast-bundle acted on by chloroiodide of zinc. 40, 41, 42. Cross-sections through young bast-cells, acted on by chloroiodide of zinc. (Sanio.)

tissue just under the bark of dicotyledonous plants). Their walls are thin, and at first nearly or quite free from pits or other markings.

They grade into three constantly recurring forms; namely, (1) parenchyma (see 254); (2) attenuated forms, often so slen-



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der as to deserve the name of fibres; (3) forms with peculiar markings at most points of contact, and thus much resembling ducts or vessels.

FIG. 59. Drawings of wood-elements. 13. Tracheïd from Tectona grandis. 14–18. Porlieria hygrometrica. 14. Conjugate substitute fibres seen in transverse section. 16. Ordinary substitute fibre after maceration. 17; 18. Conjugate substitute fibres after maceration. 19–22. Cytisus Laburnum; the elements separated by maceration. 19. Wood-parenchyma fibre. 20. Substitute fibre. 21. Simple libriform fibre. 22. Tracheïd. 23. Cross-section through the cambium and youngest wood of Cytisus Laburnum. 24–25. Ducts from Mahonia Aquifolium. 24. After maceration. 25. Longitudinal section. 26–31. Ducts from Hieracium, separated by maceration; showing the extremity only. 32–34. Ducts from Onorpordon acanthium, separated by maceration. 35. Spirally marked duct from Vitis vinifera, after maceration. 36. Libriform fibre from Jatropha Manihot. (Sanio.)

257. The drawings of wood-elements represented in Figs. 59 and 60 are from Sanio's work, and are given with his nomenclature. The cells figured in Nos. 10 and 16, termed by Sanio substitute fibres (German, Ersatzfasern), answer well to the type of prosenchyma. When these cells are much reduced in calibre, they are known as libriform fibres.

258. Ordinary prosenchyma cells usually have simple pits, but no true spirals. The pits may be round, and of the same size as those on the ducts with which they may be in contact, but sometimes they are elongated slits, and run obliquely, as shown in Fig. 60. If two of these cells are in contact, processes may extend from one cell to corresponding protrusions in the other, and thus one cell is united with the next. By careful maceration such cells can be separated, and then each appears to have one or more rows of square teeth or short tubes. It sometimes happens that the wall at the end of these intrusive tubes is broken down, thus allowing free communication between the cells.

Good examples of substitution cells are to be found in the wood of Magnolia, Liriodendron, many Leguminosæ, etc. They are not so common, however, as conjugate parenchyma cells (see Fig. 59).

259. **Woody fibres** are of two chief classes: (1) those in which the narrowed cavity is continuous throughout the whole length, and (2) those which have partitions dividing it (septate fibres).

The first class has been again divided into two groups depending upon the presence of starch, but the division is not wholly satisfactory. The first group comprises all those fibres which have a trace of protoplasm, while those of the second have also more or less starch, and generally some tannin.

All of these woody fibres resemble the bast-fibres of the inner bark of dicotyledons so closely that they have been well called libriform. They are described by Sanio, from whose paper on the subject most of these names are taken, as being always spindle or fibre-form, relatively strongly thickened, and occasionally furnished with bordered pits which somewhat resemble those of vasiform elements (264), but are smaller and less clearly defined. They never have true spiral markings, and very seldom any spiral striation. They contain during the periods of rest of vegetation in winter more or less starch, and perhaps some chlorophyll and tannin, but at other times only air.

260. The unseptate fibres, the true libriform cells, are only sparingly pitted, except in a few species like Oleander, where they are pitted on both the radial and tangential walls. The pits are generally elongated and oblique, and according to Sanio always running from left to right.

261. The cell-wall of these fibres is always lignified, and presents three layers; and in some instances there is also a layer which is plainly gelatinous, *e. g.*, in Betula and Alnus. These gelatinized fibres are not found in all of the annual rings, nor in all parts of even one ring.

262. Libriform cells are variable in length in different plants; some of the shortest occurring in Daphne Mezereum, .14 mm., and the longer in Avicennia, 2 mm. In all cases they are the longest elements in the mass of wood. They are generally simple, but occasionally branched cells are met with, as in Tilia and Cladrastis. They are sometimes irregularly grouped together, sometimes radially arranged. Species of Magnolia exhibit the latter, Ulmus the former, mode of arrangement.

263. Septate libriform cells have sometimes been confounded with wood-parenchyma; but Sanio points out the following distinctive characters: (1) they are always thicker walled; (2) they have oblique slits, while wood-parenchyma has only roundish pits; (3) they become septate only after the thickening has progressed to some extent, while in wood-parenchyma the divisions begin before the cambium cells[1] from which it is derived have begun to thicken.

Septate libriform cells are less common than any other woody element; examples, however, are not rare in Vitis, Hedera, and Rubus.

264. Vasiform elements. Neither of the two forms already considered — namely, typical wood-cells and woody fibres — has distinctive spiral markings or true bordered pits (that is, discoid markings); but another important class of wood-elements, of which mention must next be made, is characterized by such thickenings.

265. To this class of elements it is difficult to give any satisfactory name. They have been collectively termed vascular, but a large part of them are comparatively short and closed, and cannot be properly known as ducts or vessels; the name Tracheal (or Tracheary), more widely employed, is open to

[1] The immediate derivatives from the cambium, which are partly formed woody fibres, have been termed cambium fibres (Sanio : Bot. Zeit., 1863).

the objection that while it is a significant term when applied to trachea-like bodies (ducts) it is a misnomer when applied to an elongated cell wholly free from annular or spiral markings.

266. Tracheal cells are of two chief kinds: (1) those which are closed throughout, — at least until a very late stage of development; (2) those formed by rows of cells which lose their intervening partitions, and hence are thrown into a long canal, or vessel. The former are known as *Tracheïds*,[1] the latter as *Tracheæ;* for which terms may be substituted the following, applicable in nearly all cases, — *Wood-cell* and *Duct.*

The distinctive markings of tracheïds and tracheæ are bordered pits, or discoid markings, and various thickenings of which the spiral may be taken as an example.

Tracheïds and tracheæ further agree in the following point: when complete, the protoplasmic mass disappears, leaving generally no trace. The cavity is filled in a few cases with watery fluid, in some with water and air, but in most with air alone. Occasionally other matters may be found in the tracheæ, for instance, latex; but these are so exceptional as to need no further mention at this point.

267. **Vasiform wood-cells,** or **tracheïds,** are elongated and tapering cells, more or less lignified, and having peculiar markings, the principal kinds of which, although previously referred to in 133, require a more extended treatment here.

268. **Bordered pits,** called also **areolated dots** and **discoid markings,** are very common, especially in wood of gymnosperms, where they form a characteristic feature both in fossil and

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[1] But the term *tracheïd,* as usually understood, is applied to wood-cells with peculiar markings, next to be described.

The following measurements by Sanio show the difference between the length of some tracheïds and the libriform cells in the same plant: —

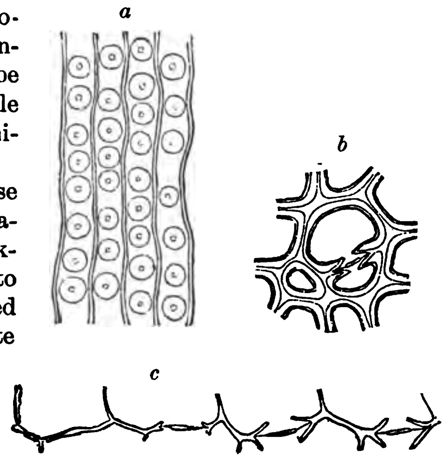
	Tracheïds.	Libriform cells.
Rhamnus catharticus	.28 mm.	.52 mm.
Æsculus Hippocastanum	.26 "	.43 "
Daphne Mezereum	.15 "	.21 "
Ribes rubrum	.49 "	.47 "

Where, however, the tracheïds alone are present, they are sometimes much longer; for instance, in Staphylea pinnata, 1 mm., and in Philadelphus coronarius, .85 mm.

According to Sanio, the bordered pits of ducts are the same as those of the tracheïds, as regards size, form, and usually as regards frequency.

Occasionally tracheïds are found which are plainly septate. It thus appears that the tracheïds form a gradation between true ducts and libriform cells with bordered pits.

recent plants. When the wood in a pine stem is cut radially, the flattened sides of the wood-cells exhibit the dotted appearance seen in Fig. 61. The number and mode of distribution of the markings in the wood-cells or tracheïds of Coniferæ are so nearly constant, that they may be used with considerable certainty in the discrimination of a few genera.



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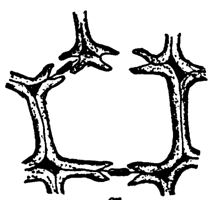
269. In a transverse section of the mature tracheïds the discoid markings are plainly seen to be pits having an arched border or incomplete dome, and it is also seen that the thin spot or pit is common to two contiguous cells. Hence the two domes, being on opposite sides of a partition-wall, have a lens shape, and the central perforations are nearly or exactly opposite each other (Fig. 62). Even in the same specimen the bordered pits vary within comparatively narrow limits both as regards the size of the disc and that of the central aperture.



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62

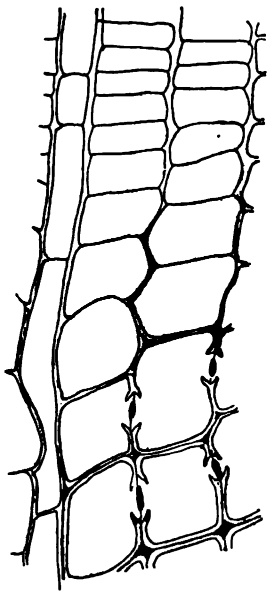
The two domes making up a single discoid marking are at first separated by a delicate plate of unequal thickness; but later this middle lamella may be broken down, and then a free passage extends from one cell to the other.

The character of the domes and the middle plate can be understood from the accompanying figures of sections of the stem of Pinus sylvestris (Figs. 62 and 63). According to Sanio, the sections should be boiled in acetic acid, in order to remove all cell-contents.

FIG. 60. Areolated or disciform markings of the wood-cells (tracheïds) of Pinus Laricio: *a*, aspect of radial walls; *b*, a transverse section; *c*, development of the markings in Pinus sylvestris. (Sanio.)

FIGS. 61 and 62. Pinus sylvestris. Transverse sections of nearly perfect and perfect discoid markings. (Strasburger.)

The cambium-cells and the youngest tracheïds have uniform and smooth walls, but in those next older there appear thin spots, which are well defined above and below, but not on the sides, for here they grade off into the thicker part of the wall. In the cells which are still older the thin places take the shape of discoid markings, and are clearly seen in any radial view. Comparison of radial with transverse sections shows that at the margins of the thin places a portion of the wall extends as a slight projection upwards, and partly over the spot. In the more mature form the thin place is still retained as a delicate plate separating the two cells, but easily broken down perhaps in further growth.



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270. *Scalariform markings* (see 134) are especially abundant in ferns. The bordered pits are much elongated, and appear as clefts with only narrow portions of the wall between them (Fig. 64 *l*). They often follow each other with as much regularity as the "rounds" of a ladder, whence the name (from *scalaria*, — a flight of steps). They are more commonly found in

DUCTS.

271. Ducts, or Tracheæ, are variously marked by pits, and by the thickenings described in Chapter I. Some of the more common forms of dots are shown in Fig. 64.

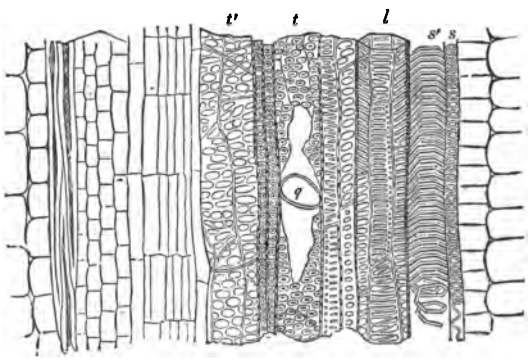
Spiral, annular, and reticulated markings are all formed by the thickening of parts of the wall by which narrow lines or bands are produced on the inner surface. In these cases the portions of the wall which are not thickened are often of extreme tenuity, and break upon slight pressure or strain, permitting the spiral to uncoil or the rings to separate (Fig. 64, *s s'*).

272. **Spiral markings.** The number of threads or narrow bands varies from one to fifteen or even twenty, the latter in the petioles of Musa.[1] They wind, as a rule, from right to left;

[1] De Bary: Vergleichende Anatomie, 1877, p. 163.

FIG. 63. **Pinus sylvestris.** Cross-section through the cambium and young wood-cells. (Strasburger.)

but, according to Mohl, from left to right in a few plants. Thus in the wood of Vitis vinifera, Berberis vulgaris, and some others, they run from left to right in the ducts first formed, but in the reverse direction in those which are produced later. And by interruption of the spiral it may have two directions in the same duct, as in those of Cucurbita.[1] The steepness of the



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spiral depends in part on the age of the cell, or vessel, — at least in some cases. According to Mohl, "if the vessel is developed in an organ which has already completed its longitudinal growth, the turns of the spiral lie close together; but if the organ undergoes elongation after the completion of the development of the vessel, the turns of the fibre are drawn far apart by the stretching which the vessel suffers; consequently very loosely wound spiral vessels are usually found in the posterior first-formed portion of the vascular bundle nearest to the pith, while those lying nearest the bark have close convolutions."[2]

273. **Annular and reticulated markings** have been regarded as mechanical modifications of spirals, and it is true that intermediate forms exist between these types. For instance, tightly wound spirals are nearly annular, and in some cases there are threads which run either vertically or obliquely from one part of a spiral to the contiguous thread. But even in the youngest states of some ducts the markings appear as rings or as a net-

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[1] Mohl: Vermischte Schriften, 1852, pp. 287, 321, Ueber den Bau der Ringgefässe.

[2] Mohl: Vegetable Cell, Eng. Trans., 1852, p. 19.

Fig. 64. Vertical radial section of hypocotyl of Ricinus communis, illustrating different markings of ducts; *t' t*, pitted; *l*, scalariform; *s' s*, spiral, the spirals beginning to uncoil. (Sachs.)

work. While, therefore, they may and probably do have a common origin with spirals, it is not necessary to assume, nor is it probable, that they have resulted from mechanical displacements of them. The relative positions of the separate rings may be explained in the same way as the steepness of the spirals.[1]

274. Cases are met with, in which projections from the wall may extend nearly or quite across the cell-cavity, somewhat after the manner of beams. Such cross-beam cells or ducts are called trabecular. A good example can be found in some of the tracheïds of the leaf of Juniperus communis.[2]

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[1] "The notion was extensively held that the spiral fibre could not follow the expansion which the vessel underwent during its growth, and tore up into fragments which were again united into rings, and thus brought about the formation of annular vessels. Completely as this idea, which was a contradiction to all observation, had been refuted by Moldenhawer, it remained a standing article in all phytotomical writings up to Meyen's Physiologie" (Mohl: Vegetable Cell, p. 21).

[2] De Bary: Vergleichende Anatomie, p. 171.

The following measurements of wood-cells and ducts are given by Wiesner (Die Rohstoffe des Pflanzenreiches, 1873, p. 525): —

	Average diameter of wood-cells.
Rhus Cotinus	7.5 μ.
Lonicera Xylosteon	9.8 "
Salix Capræa	11.0 "
Viburnum Lantana	22.0 "
Alnus glutinosa	25.0 "
Fraxinus excelsior	28.0 "

	Average diameter of ducts.
Hæmatoxylon Campechianum	112 μ.
Cæsalpinia Sappan	120 "
Ochroma Lagopus	140 "
Fraxinus excelsior	140 "
Ulmus campestris	158 "
Tectona grandis	160 "
Juglans regia	220 "
Carya alba	248 "
Quercus sp.	200 to 300 "

The ducts in the foregoing examples are so large that in cross-section they can easily be seen by the naked eye. The following are considerably smaller: —

Tilia sp.	60 μ.
Acer sp.	71 "
Alnus sp.	76 "
Rhus Cotinus	80 "
Betula sp.	85 "

275. **Tyloses.** If a cell still growing is in contact with a duct at one or more of its perforations, the cell may intrude into the cavity of the duct, and to a considerable extent. Such intrusive growths are known as Tyloses (German, Thyllen).

If the intrusive portion of the tylosis further multiplies, producing new cells, the cavity of the duct may contain a confused mass of irregular cells of various shapes and sizes. Such masses are often found in the ducts of Quercus alba, Q. castanea, Q. macrocarpa, Q. tinctoria, Q. virens, Castanea vesca, Carya alba, C. olivæformis, C. amara, Juglans nigra, Sassafras officinalis, Morus rubra, Maclura aurantiaca, and Robinia Pseudacacia. In the latter they are especially striking.[1]

BAST-FIBRES (LIBER-FIBRES).

(Sclerenchyma of many recent German authors.)

276. The name *bast* was originally given to the inner bark of the linden (bass-wood), and hence originated its use as a prefix in "bast-matting," etc.; the name *liber* was applied in a more general way, namely, to any smooth inner bark (upon which one could write). That which imparts strength to inner bark, making it of use in the arts, consists of long and tough cells with very much reduced calibre; but these are not confined by any means to inner bark. Owing to this fact, some have thought best to abandon the terms bast and liber for such cells, and adopt, on account of their firmness, a term formerly given to grit-cells, namely, sclerenchyma; the older terms, however, are not likely to lead to confusion, whereas the other might. It is in the bark of dicotyledons that liber-cells or liber-fibres occur most abundantly.

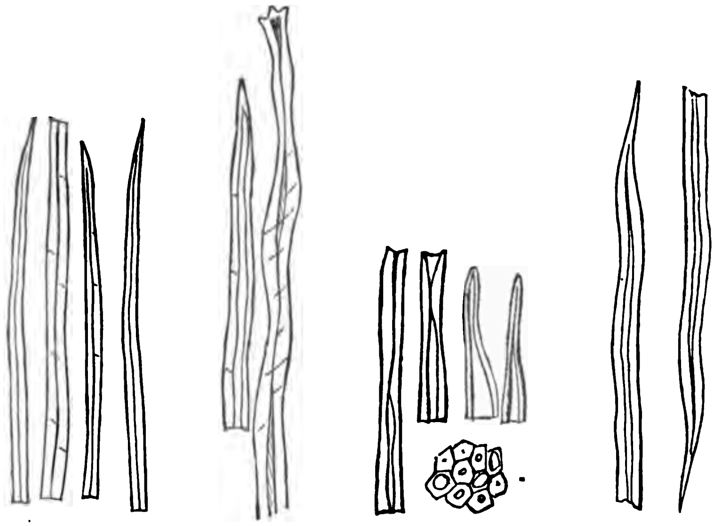
Their prevailing shape is that of a slender spindle, which may taper simply, or may be somewhat forked at the extremity.

The following can be seen only under a lens: —

Euonymus Europæus	20 μ.
Fagus sp.	28 "
Cratægus sp.	30 "
Ligustrum sp.	36 "
Pyrus communis	40 "

[1] Mr. P. H. Dudley, who communicates some of the names in this list, adds in his note: "So far I have never found any tyloses in ducts with scalariform markings."

Occasionally fibres which are very much branched are met with, notably in the leaves of Camellia, for instance common tea; see Fig. 68. Generally the walls are thickened unevenly, even forming conspicuous projections into the cavity of the cell; while some fibres have regular and characteristic markings, a few



a *b* *c* *d*

65

of which are shown in Fig. 65. Septate forms are occasionally found. The change in the character of the cell-wall which accompanies the thickening is essentially lignification, like that observed in wood-cells and ducts. It is generally said that the walls of liber-cells are less brittle than those of the elements of wood, and this is commonly so; but there are some flexible wood-elements, and there are, on the other hand, some very brittle fibres of sclerenchyma. The thickening of the wall in liber-cells takes place not only in different degrees, but with variations in the amount of infiltration of foreign matters, which give rise to differences in the behavior of the fibres with reagents. In a few cases the inner part of the wall is somewhat gelatinous

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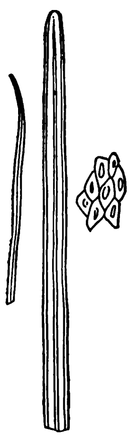
FIG. 65. Fragments of some of the more common bast-fibres used in the arts. $\frac{300}{1}$.

a, Flax, Linum usitatissimum. (Wiesner)
b, Hemp, Cannabis sativa. (Schacht.)
c, Jute, Corchorus capsularis. (Wiesner.)
d, China-grass, Bœhmeria nivea.

and possesses the power of swelling in water and in dilute acids (compare Collenchyma); in some others the outer part of the wall is gelatinous, while the inner is hard. Morus alba, Gleditschia triacanthos, and Robinia Pseudacacia are examples of the first, Astragalus falcatus of the second, condition (Sanio).

277. One of the most striking characters of the bast-fibres of many plants is the abundance of crystals found therein. Excellent examples are afforded by the inner bark of some of our ligneous plants (294).



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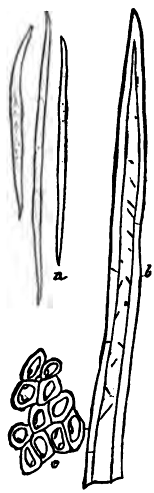

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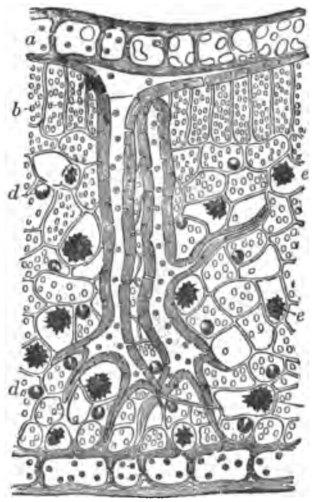

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278. The firm attachment of fibres to those above and those below them has given rise to erroneous ideas relative to the length of single fibres, as the table on the following page shows.[1]

By careful management it is possible to isolate a connected thread of fibres of great length; the value of fibres for textile purposes depends largely upon this fact.

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[1] The table on page 90 has been compiled from data given by Wiesner and also by Vetillart, which are here rearranged for greater convenience of reference.

FIG. 66. Fibre of Agave Americana: *a* and *b*, $\frac{80}{1}$; *c*, $\frac{250}{1}$. Only the upper part of each fibre is shown in the left-hand figures. The right-hand figure shows a cross-section of a group of cells.

FIG. 67. Fibre of Coir (Cocos nucifera): *a* and *c*, $\frac{80}{1}$; *b*, $\frac{250}{1}$. *a* shows three separate and complete fibres, *b*, the upper part of a single one, *c*, a cross-section of a group of cells.

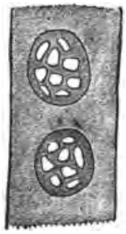
FIG. 68. Transverse section through leaf of Camellia (Thea) viridis, showing: *a*, epidermis; *b*, branched liber-cell; *d*, oil-drop; *e*, crystals. (Mirbel.)

THE CHARACTERISTICS OF FIBRES.

Name of Fibre.	Reaction with Cuprammonia.	Reaction with iodine and sulphuric acid.	Reaction with anilin sulphate.	Length of raw fibre, cm.	Width, mm.	Length of the bast-cells composing the fibre, mm.	Width of the bast-cells composing the fibre. Limit of size, mm.	Width of the bast-cells composing the fibre. Average size, mm.
Raw flax fibre (Linum usitatissimum).	Soon attacked and almost entirely dissolved.	Colored blue.	Remains uncolored or nearly so.	20–140	.04–.62	20–40	0.012–0.026	0.015–0.012
Raw hemp fibre (Cannabis sativa).	Clean fibre dissolved.	Greenish-blue to pure blue.	Colored faint yellow.	100–300		10+	0.015–0.028	0.016–0.019
Raw jute (Corchorus capsularis).	Bluish color and more or less distinct swelling.	Yellow to brown.	Golden-yellow to orange.	150–300	.03–.14	0.8–4.1	0.010–0.021	0.016
Raw esparto fibre (Stipa tenacissima).	Bright green.	Rusty red.	Egg-yellow.	10–40	.09–.5	0.5–1.9	0.009–0.015	
Bromelia Karatas.	Bluish color and marked swelling.	Reddish-brown.	Golden-yellow.	120	.15–1.2	1.4–6.7	0.027–0.042	
Raw fibre of aloe (Aloe perfoliata).	Bluish color and feeble swelling.	Reddish-brown.	Golden-yellow.	40–50	.075–.105	1.3–3.7	0.015–0.024	
New Zealand Flax (Phormium tenax).	Bluish color and more or less distinct swelling.	Varies with purity of fibre, being yellow, green, or blue.	Remains uncolored or nearly so.	80–110	.042–.12	2.5–5.6	0.008–0.019	0.013
China grass (Bœhmeria nivea).	When "cottonized," quickly acted upon and almost completely dissolved.	Copper red to blue.	Remains uncolored or nearly so.			Up to 220	0.040–0.080	0.050
Ramiefibre (Bœhmeria tenacissima).	When "cottonized," quickly acted upon and almost completely dissolved.	Copper red to blue.	Remains uncolored or nearly so (hardly perceptible yellow).			Up to 80	0.016–0.126	
Coir (Cocos nucifera).	Perceptible swelling and pronounced blue color.	Reagent not applicable on account of the color of the fibre.	Not applicable on account of the color of the fibre.	15–33	.05–.30	0.4–0.96	0.012–0.020	0.016
Agave (Agave Americana).	Swells and becomes somewhat blue.	With iodine solution yellow, on the addition of sulphuric acid greenish or brownish.	Yellow.	100	.10–.46	1.02–2.2	0.016–0.021	0.017
Musa (Musa textilis).	Blue color and feeble swelling.	With iodine solution yellow, on the addition of sulphuric acid golden-yellow to greenish.	Pale yellow.	750	.010–.28	2 0–2.7	0.012–0.046	0.029

III. Cribrose-cells, Sieve-cells, or Sieve-tubes.

279. In the inner bark of stems of dicotyledons with normal structure certain long cells of peculiar character are found associated with bast-fibres. They are of tubular or prismatic form, and are characterized by the presence of circumscribed panels in the walls, in which are numerous fine perforations permitting communication between contiguous cells. The panels are known as sieve-plates; the perforations, as sieve-pores. These cells constitute an essential, though by no means always a conspicuous, element of fibro-vascular bundles. Taken collectively, they may be known as cribriform tissue. By their union end to end they appear like long tubes with the continuity interrupted here and there by cross partitions. These partitions which separate the individual cells are sometimes nearly horizontal, but more generally oblique, as shown in the annexed figures where they mostly cut the lateral wall of the cell at a sharp angle.



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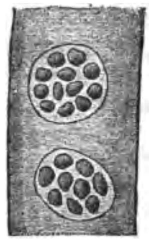

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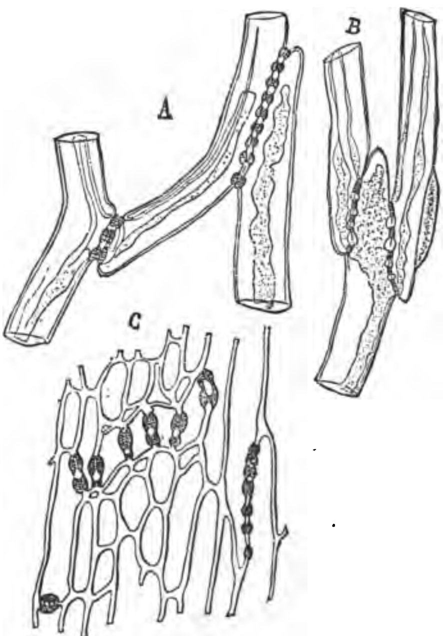

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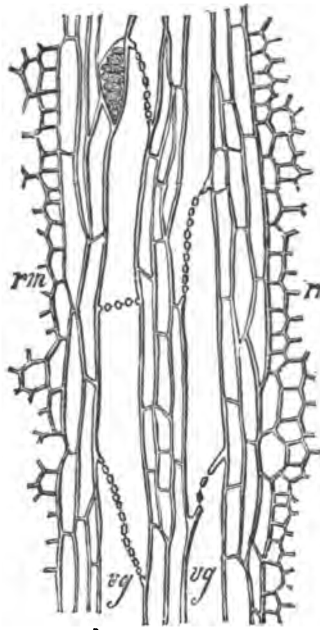
280. The walls of cribrose-cells are never lignified; on the contrary, they are

Fig. 69. Pinus sylvestris. Face view of radial wall containing two cribrose-plates wholly deprived of callus. $\frac{1125}{1}$. (Janczewski.)

Fig. 70. Pinus sylvestris. Radial wall of a young tube, face view. The future cribrose-plates are composed of callus-cylinders, filling the meshes of a cellulose network. $\frac{1125}{1}$. (Janczewski.)

Fig. 71. Cribrose-cells in Vitis vinifera: *A*, transverse anastomosis of two cribrose-

very soft and colorless. Owing to their yielding character, it is not easy to make satisfactory sections for their demonstration, from fresh material; it is better to keep the material in alcohol for a while, or to dry it carefully, as Russow advises. All sections, to show the sieve-cells,



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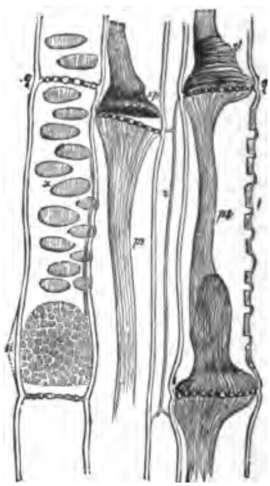

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must be very thin. The following measurements of single large cells given by de Bary serve to indicate their wide range in size:

	Length, mm.	Transverse diameter, mm.
Cucurbita Pepo	.370 –.450	.045
Calamus Rotang	2.000	.030 –.050
Potamogeton natans	.275	.025
Vitis vinifera	.6	

281. The sieve-plates occur at the points of contact of sieve-cells. They are always found at the ends of the cells, and may

cells isolated by maceration; the septa are in their winter state. *B*, branching of cribrose-cell isolated by maceration. *C*, tangential section across a medullary ray, showing the transverse anastomosis of cribrose-cells; the callus at the septa is in its winter state. (Wilhelm.)

FIG. 72. Cribrose-cells in Vitis vinifera. Longitudinal tangential section (beginning of July) through the bast of a stem 1 cm. thick; *vq*, cribrose-cells, the oblique as well as one horizontal perforated septum cut longitudinally. The face of one septum, however, is shown at the upper part of the figure; *rm*, medullary rays. (De Bary.)

FIG. 73. Cucurbita Pepo Longitudinal section showing terminal sieve-plates at *q*, *q*, and a lateral one at *si*; *ps*, contracted protoplasm. (Sachs.)

likewise appear upon the lateral walls. When the terminal partitions are horizontal, or nearly so, they are cross-plates, the whole partition forming one plate; but on very oblique ends the plates may be separated and lie in one or more rows. The plates on the walls are smaller and irregularly distributed. On parts of the wall contiguous to cells of any other kind there may be dots; there is yet some doubt as to whether they are perforations.

The diameter of the sieve-pores is given by Mohl as not far from 2 μ; but although some are even 5 μ in diameter, the former figure is too high for the average.

282. That which is characteristic of sieve-plates, in distinction from groups of perforations elsewhere found, is a thickening mass, of bluish lustre and apparently homogeneous structure, known technically as the *callus*. It is best shown at the terminal plates, especially after the application of a solution of iodine which turns it yellow, and makes it more sharply defined. In concentrated sulphuric acid and in the strong alkalies this mass swells up so as to be several times its original size; and in the former it soon dissolves, leaving only slender threads in its place. The character of the callus

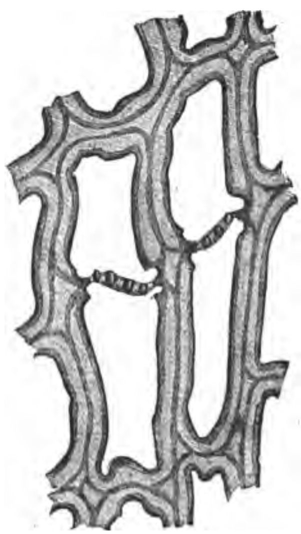

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Fig. 74. Pinus sylvestris. Transverse section across four entirely passive tubes, which are somewhat compressed laterally. $\frac{1165}{1}$. (Janczewski.)

Fig. 75. Pinus sylvestris. Terminal partition. A tube inserted upon the radial wall. The pores of the terminal partition are filled with warty callus, in the midst of which the cellulose network may always be seen; in the pore of the radial wall the callus is completely smooth and round. Tangential section. $\frac{1165}{1}$. (Janczewski.)

varies with the age of the cell and with the time of year, as shown in the figures.

283. Anilin blue is the best pigment for bringing out the form of the callus clearly. If, as Russow[1] recommends, its use be supplemented by that of Schulze's iodide, the callus may be seen to be made up of at least two portions, distinguished by the depth of color. In young and active cribrose-cells the callus usually appears to be a gelatinous layer on each side of the sieve-plate; in most old cells it is no longer seen.

284. Contents of the cells. In the younger and active state just referred to, the cells contain a watery liquid which holds more or less granular matter, and the walls are lined by a delicate film of protoplasmic substance. That the callus is also of a protoplasmic nature is not clear, although some of its reactions suggest this. It frequently contains minute granules of starch, which sometimes give a bluish-brown color with iodine, like starch which has been acted on by diastase. Russow thinks that a ferment is present in the cells in their active state. When old, most cells lose not only the callus but also the greater part of their other contents. In active cells there are frequently found very small but brilliant globules which are albuminoidal. All the contents above mentioned vary within certain limits at different periods of the year.

285. The sieve-cells of the higher cryptogams have been shown by Janczewski[2] to be nearly if not quite imperforate at all seasons. In gymnosperms, they pass through two periods: the first, or the evolutive, in which the plates produce the callus, the cells themselves containing parietal protoplasm; the second, or passive, stage, in which the protoplasm disappears entirely, and communication between the contiguous cells occurs. In monocotyledons and dicotyledons the cells have four periods; namely, the evolutive, the active, the transitory, and the passive.

IV. Latex-cells, Latex-tubes.

286. Certain plants when wounded exude a milky juice known as latex. They belong to widely separated orders; for instance, to Papaveraceæ, Campanulaceæ, Asclepiadaceæ, Urticaceæ, etc.

The cells in which latex occurs are characterized by a softness of cell-wall which renders them easily compressible; hence,

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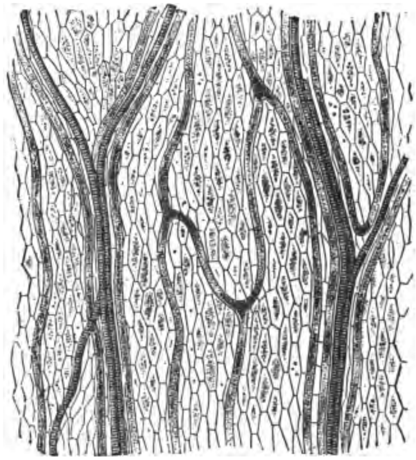
[1] Annales des Sc. nat. bot., sér. 6, tome xiv., p. 167.
[2] Annales des Sc. nat. bot., sér. 6, tome xiv., p. 50.

bounded by turgescent tissues, their contents readily escape through any incision.



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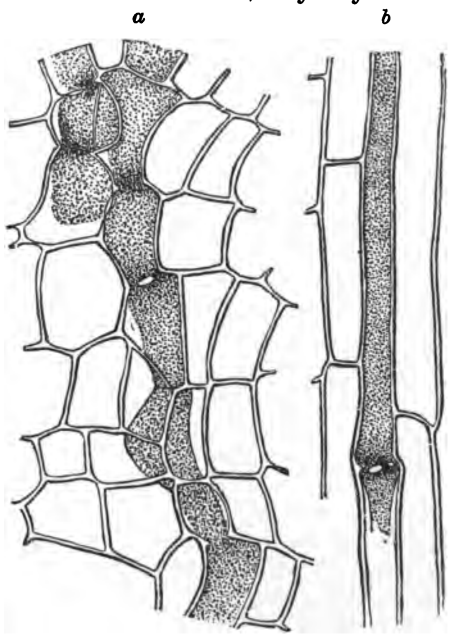
Latex-cells are not restricted to any one organ of the plant, but may, and generally do, occur in all parts, and may be associated with more than one tissue-system. They are, however, usually found in parenchyma, and run in the same general direction as the fibro-vascular bundles near which they lie. For convenience, they may be divided into the simple and the complex.



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287. The simple forms are single cells, which may be much and variously branched. Subsequent to the development of one of these cells in a plant, and when it has extended its ramifications throughout the different organs, a new cell may independently give rise to new branchings, and to a new system, some of the branches of the two cells perhaps becoming confluent. Good examples of the simple forms are af-

FIG. 76. Longitudinal section through a sepal of Chelidonium majus, showing latex-tubes. (Weiss.)

FIG. 77. Latex-tubes composed of confluent cells: *a*, in the root; *b*, in the stem of Chelidonium majus. (De Bary.)

forded by the following orders, — Asclepiadaceæ, Apocynaceæ, and Euphorbiaceæ.

The complex forms consist of rows of cells which coalesce to form a latex-system. The individual cells may have their partition-walls broken down very early, a mere vestige of them remaining; or the partitions may be simply perforated, so as to allow a free communication between contiguous cells. Moreover, the confluent cells may be conjoined laterally, thus constituting a complicated network which runs through the plant.

288. Occasionally roundish groups of perforations resembling in a few particulars those of sieve-plates are found in the latex-cells of Papaver and some Cichoraceæ; but they are coarser and more irregular, and are devoid of the peculiar sieve-plate structure. Moreover, no true intermediate forms have been proved to exist between the two kinds.[1]

289. The wall of a latex-cell is often very thin, and free from any markings; but with even slight increase of thickness, striations and stratification make their appearance, projections may extend into the cavity of the cell, or even spirals may be present. In character, the cell-wall possesses many of the peculiarities of collenchyma, especially in its behavior with iodine.

290. That the cells contain a protoplasmic lining is highly probable, but this has not yet been satisfactorily demonstrated. The liquid in the cells consists of granular matters suspended in a watery fluid, and imparting to it a milky appearance. Often the color of the liquid is yellow, as in Argemone, or orange, as in Chelidonium. The watery fluid contains in solution sugar, gums, resins, traces of albuminoid matters, and various principles, for instance, alkaloids (like morphia), and organic acids.

The suspended matters are of minute size, with the exception of peculiar forms of starch-granules. When perforation is made in the latex-system of a turgescent stem, these granules can be seen to move towards the point of injury. The same movement can be observed when the pressure on one part of the stem is materially increased; and hence arose the erroneous belief that there is a circulation of latex.[2]

291. Upon exposure to the air latex coagulates, and forms upon drying a sticky, elastic mass, which in some plants is sufficiently abundant to furnish the india-rubber of commerce.

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[1] D. H. Scott: On the development of articulated laticiferous vessels. Journ. Mic. Science, 1882, p. 144. An interesting account is also given by de Bary, from notes by Schmalhausen, Vergleichende Anatomie, p. 205.

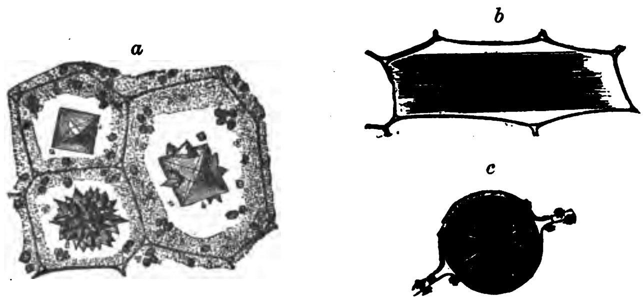
[2] Schultz: Die Cyklose des Lebenssaftes in den Pflanzen, 1841, p. 282.

RECEPTACLES FOR SECRETIONS.

292. Individual cells (idioblasts) may differ greatly from their neighbors as respects their contents. Such cells may be well named after their characteristic contents; as crystal-cells, resin-cells, mucilage-cells, tannin-cells, etc.

293. They vary much in shape and size. Frequently they are not readily distinguishable from their immediate neighbors by anything except their contents. In other cases, however, they may assume forms widely different from those of the cells around them, and may also be distinguished by their size. They are often so associated together as to form "glands."

294. *Crystal-cells.* These sometimes, as de Bary points out, curiously resemble the shape of the crystal or groups of crystals



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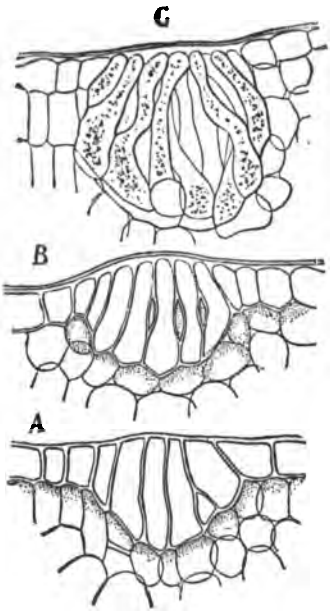
which they contain. Thus globular clusters are generally contained in spherical cells, elongated prisms in elongated cells (as in Quillaja). "In many trees each cambium-cell (as it develops into a bast-fibre) may be divided by diagonal partitions into numerous (20 to 30) chambers, the height of which is about the same as the width, and each is filled by a crystal or a small cluster. In this case the general outline of the original cambium-cell remains unaltered, and the whole row of compartments may be isolated as a chambered fibre."[1] The bast-cells containing crystals have been already noticed.

295. *Resin-cells.* In a large number of plants soft viscid substances are present, which exude when the tissues are wounded. They may be roughly classed into (1) *Balsams*, in which resinous matter is mixed with a considerable proportion of

[1] De Bary: Vergleichende Anatomie, p. 145.

FIG. 78. Crystal-cells: *a*, from the petiole of Begonia manicata; *b*, a cell with raphides, from Lemna trisulca; *c*, from Phallus caninus. (Kny.)

one or more essential oils, forming a thickish liquid; (2) ***Resins,*** which have comparatively little essential oil commingled, and are of various grades of hardness; (3) *Gum-resins*, or resins having more or less mucilaginous or gummy matters. To the latter class are sometimes referred the products left by the drying



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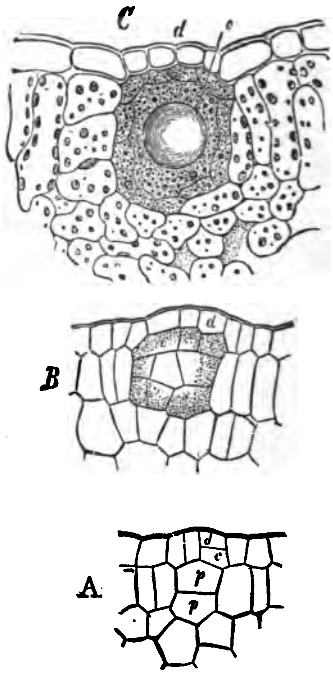

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of many milky juices (latex); of such, caoutchouc is an example. All the foregoing substances may be found in single cells, which are of very diverse forms.

296. Roundish cells of this character are found in the Magnoliaceæ and some Compositæ, etc. Long cells are to be detected in some Liliaceæ, etc., and they are connected by many intermediate forms with resin-ducts arising from the confluence of several cells. On the other hand, they pass by various gradations into structures which are generally referred to the latex-

FIG. 79. Transverse section through the leaf of Psoralea hirta; the epidermis consisting of one layer with some of the tissue shown on both sides of the gland: *A*, very young state in which the secretion is not yet present; *B*, somewhat older, secretion commencing; *C*, mature state. (De Bary.)

FIG. 80. A "gland" in Dictamnus Fraxinella: *A*, *B*, early stages; *C*, mature state; *p*, *p*, *c*, mother-cells of the gland-tissue; *d*, the covering layer forming a continuation of the epidermis; *o*, a large drop of oil. (Rauter.)

system. To this system should perhaps be referred also numerous cases of pigment-cells, like those in the roots of madder and rhubarb; also the peculiar bodies seen in the periphery of the pith of Sambucus, and the milk-sacs of some species of Acer.

297. *Mucilage-cells* are larger than the surrounding cells, and sometimes closely resemble intercellular spaces filled with mucilaginous matter. In some instances the mucilage is distinctly referable to changes in the contents of the cell, in others to a disorganization of a portion of the wall, while in still others both sources may be recognized.[1]

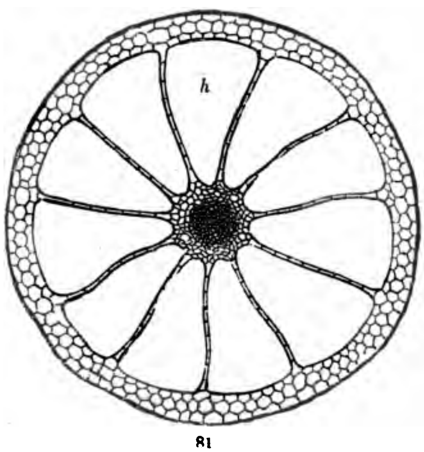
298. Cells containing tannin in very large amount are frequently met with, but they do not call for special remark.

299. Resins and the like are found not only in single cells but also in spaces formed by the breaking down of the intervening walls of cell-clusters of various shapes; hence various forms of receptacles for these substances may be looked for.

INTERCELLULAR SPACES.

300. The walls of cells still capable of division are generally in unbroken contact; but as differentiation goes on they may become separated more or less by unequal growth or by a breaking down of intermediate cells.[2] The intercellular spaces thus formed may be mere chinks, or they may become chambers of large size. They may contain merely air, or air and watery sap, or most of the matters described in the previous sections.

Air-spaces in the looser tissues of plants are generally so con-



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[1] The details of this subject can be found in Prings. Jahrb., v. 161 (Frank), and Annales des Sc. nat., sér. 6, tome i. p. 176 (Prillieux).

[2] The first mode of development of intercellular spaces has been termed *schizogenic*, the latter *lysigenic*; moreover, a distinction may be made between those intercellular spaces which are formed when the tissues begin to differentiate, —*protogenic*, — and those formed in older tissues, — *hysterogenic*.

FIG. 81. Transverse section through the stem of Elatine Alsinastrum, showing large intercellular spaces, *h*, containing air. (Reinke.)

nected throughout the plant, and communicate so directly with the stomata, that they constitute an apparatus for bringing the interior of the structure into close relations with the outer air. Sometimes the aggregate volume of the air-spaces is very large in proportion to the volume occupied by the cells themselves.[1]

In composition, the air within the plant usually differs from that of the atmosphere in containing a larger proportion of nitrogen. If the air-spaces are much smaller than the cells which surround them, they are termed *interstices;* if about as large as the cells, *lacunæ;* if conspicuously larger, *air-passages* or air-chambers. Two chief forms of lacunæ are distinguished by de Bary; namely, cavities surrounded by cells which are more or less branched, and those surrounded by plates of cells. Good examples of the former are afforded by many water-plants, rushes and the like; of the latter, by the stems of many Araceæ, for instance, Acorus Calamus.

301. The continuity of the larger air-passages may be interrupted by plates crossing at an angle (generally slightly oblique). Such dividing plates, termed *diaphragms*, are frequently complicated in their structure.

302. Hairs, sometimes much branched, are found in the larger air-passages of many plants. These form the stellate structures in the Nymphæaceæ, and the "H-like" cells in some Araceæ.

303. Intercellular spaces, usually those of small size, may contain water together with air. This is the case in the cavities under the water-pores of Fuchsia, etc.

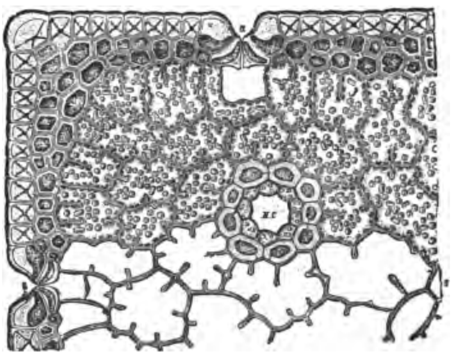
304. When intercellular spaces contain resins, oils, and the like, they constitute, together with the simple cells described in 295, the structures loosely called *internal glands.* Often these are merely irregular spaces left by the breaking down of one or

[1] The following measurements are taken from Unger (Sitzungsb. d. Wiener Akad., xii. 373).

Name of plant.	Parts examined.	No. of parts by volume of air in 1000 parts of the plant.
Paspalum setaceum.	Four leaves with their sheaths.	68
Musa sapientum.	Piece of the leaf-stalk.	480
Nicotiana Tabacum.	Leaf with leaf-stalk.	256
Brassica Rapa.	Leaf with leaf-stalk.	175
Begonia manicata.	One leaf with its stalk.	66
Camellia Japonica.	Two leaves with their stalks.	224
Prunus Laurocerasus.	One leaf with its stalk.	·219
Aucuba Japonica.	One leaf with its stalk.	273
Ardisia crenulata.	Four leaves with short stalks.	220

more cells, but they sometimes have a remarkable regularity of form and clearness of outline.

It has been observed that these spaces filled with resinous and other matters are not, as a rule, met with in the plants which are provided with the simpler receptacles, consisting of single cells or small groups. De Bary classifies these resin-passages and



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spaces as follows: (1) those passages which contain mucilage and gums, as those in the Cycads, species of Canna, Opuntia, and some Araliaceæ; (2) resin-canals and cavities containing resins, ethereal oils, emulsions of resinous gums, etc., variable in quality in different cases; *a*, passages or canals, as those in Coniferæ, Alismaceæ, Aroideæ, the tubuli-flowered Compositæ, Umbelliferæ, Araliaceæ, Anacardiaceæ; *b*, short cavities, as in species of Hypericum and the true Rutaceæ, many species of Oxalis and Myrtaceæ, and some species of Lysimachia. The cells which surround the more complete cavities are so different from the neighboring parenchyma that they have been termed, collectively, the *epithelium* of the spaces.

It is not fully known in what way the various resinous and mucilaginous matters are produced in the cavities. In some instances, at least, the matters appear at a very early stage of the development of the cells which are afterwards broken down to form the cavity. The special cases, like those of the Myrtaceæ, in which the cavities contain oil, are best for purposes of study, because they are so frequently to be found in the thinnest leaves, and at an early stage of development.

Fig. 82. Transverse section of part of leaf of Pinus Laricio, showing a resin-passage, *HC.* (Kny.)

CHAPTER III.

MINUTE STRUCTURE AND DEVELOPMENT OF THE ROOT, STEM, AND LEAF OF PHÆNOGAMOUS PLANTS.

GENERAL CONSIDERATIONS.

305. THE tissue elements, described in the preceding chapter, are arranged in various ways to form and connect the organs of the plant. If elements of the same kind are united, they constitute a *tissue*, to which is given the name of those elements; thus parenchyma cells form parenchyma tissue or simply parenchyma; cork-cells form cork, etc. A tissue can therefore be defined as a fabric of united cells which have had a common origin and have obeyed a common law of growth.

Tissues are united to form *systems;* systems, to form *organs.*

306. In nearly all plants with which the present treatise deals there is some kind of framework consisting mainly of the more elongated cells and ducts. This framework runs throughout the entire organism. It is surrounded by parenchyma, in which other tissue elements may also occur; the epidermis in some of its modifications covers the whole.

307. The three chief systems found in plants are, therefore, the fascicular, the cellular, and the epidermal; and these correspond in a general way to three classes of functions. In the cellular system are found the active cells by which assimilation, the proper work of the plant, is effected; the fascicular system is largely conductive, and serves also important mechanical ends; the epidermal system brings the assimilative apparatus of the plant into safe relations with the surroundings.

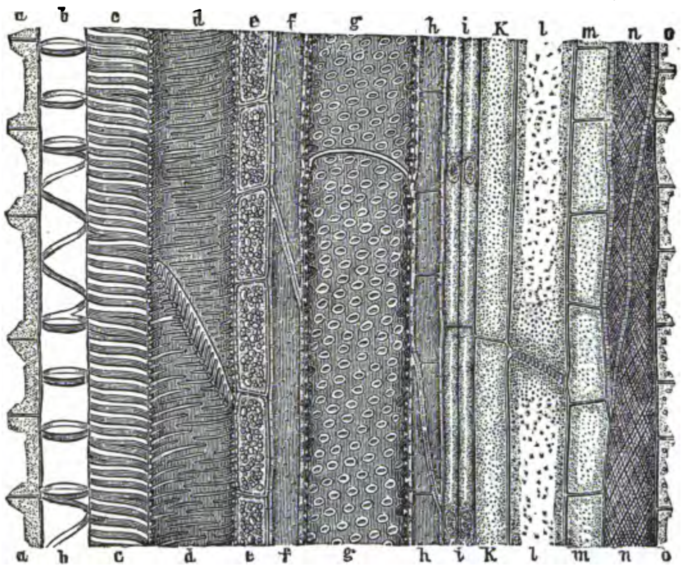
No discussion of the cellular and epidermal systems, introductory to a special consideration of them as they occur in the different organs, is needed; but some general statements relative to the fascicular system will obviate repetitions later.

308. The fascicular system, in its most complete development, comprises the following tissue elements, which occur in very different proportions in different cases, — prosenchyma in the widest sense, including wood-cells of all kinds, ducts, fibres, and cribrose-cells; together with some commingled parenchyma. With

the exception of the parenchyma, all these elements are elongated and are arranged in various sorts of fascicles or bundles, whence the name, the *fascicular system*. Since fibres and vessels play such an important part in the composition of this system, it has been also called the fibro-vascular system, and the bundles, fibro-vascular bundles.

309. When reduced to its lowest terms, a fibro-vascular bundle consists of two tissue elements, namely, cribrose-cells and tracheal cells, the latter being sometimes replaced either wholly or in part by ducts.

310. The two elements are usually associated with some parenchyma and with a considerable proportion of long bast-



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fibres; but, while preserving a general uniformity of structure throughout, a bundle may become considerably changed in composition during its course. This is well shown by comparing sections taken at some distance from each other; for instance,

FIG. 83. Longitudinal radial section of a collateral fibro-vascular bundle, from the stem of a dicotyledon: *b*—*i*, wood; *i*—*n*, liber; the wood comprises, *b*, a narrow annular duct, *c*, wider spiral duct, *d*, a duct with septum, *e*, woody parenchyma, *f*, woody fibre, *g*, wide duct with areolated pits, *h*, septate woody fibres; the liber comprises, *n*, liber-fibres, *m*, short parenchyma, *l*, cribrose-cells, *i*, cambium, *k*, long parenchyma or cambiform. (Kny.)

one made in the middle of the course of a bundle with one near its extremity.

311. The cribrose part of the bundle may also be termed its liber-portion or bast-portion; the tracheal, its woody portion. These terms are not liable to be confounded with any others, since it is with the cribrose portion that the well-known bast-fibres or liber-fibres are associated, while it is in the tracheal portion that all the constituents of wood are found.

312. For the first term (bast-portion), Nägeli has introduced the word Phloëm; for the second (wood-portion), Xylem. In this treatise these terms will be used interchangeably with the others. But the woody portion of a bundle is sometimes very far from being conspicuously lignified, and the bast-portion may be much reduced.

313. The three principal ways in which the elements of bundles are arranged are: 1. A single strand of liber has one side in contact with a single strand of wood, the two running side by side, — the *collateral* bundle. This mode of arrangement is common in the stems of phænogams. A variety of the collateral bundle has a strand of liber on each side of the wood, or, conversely, a strand of wood on each side of the liber, — the *bicollateral* bundle. 2. The strands of liber and wood are in different radii, — the *radial* bundle. This is the most common mode of arrangement in roots. 3. A strand of one element is wholly enveloped by the other element, — the *concentric* bundle. These modes of arrangement will be further discussed under "Roots" and "Stems."

314. The bundles are surrounded by parenchyma; but this is very frequently limited at the periphery of the bundle by a cylinder formed of closely united parenchyma cells, which contain considerable starch. The *endodermis* is a special case of this structure, in which the cells are more or less distinctly cutinized. When this enveloping cylinder is well defined, it is known as the bundle-sheath.[1]

315. At first, each bundle consists of similar cells (*procambium*), some of which differentiate into fibres, vessels, etc. Bundles in which all the procambium cells become permanent cells are *closed;* those which retain an inner portion (*cambium*) capable of further differentiation are *open.*

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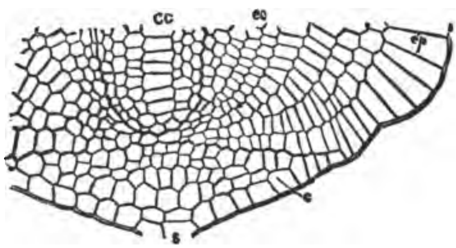
[1] In a great number of instances it is convenient to refer to the same structure the long and firm bast-cells which are found at one side of the bundle; but the subject, when examined from the point of view of development, especially when the vascular cryptogams are taken into account, presents so many difficulties that it may be here left without further treatment.

316. As regards the course of the bundles through the plant, it is sufficient to note here that they are variously combined in the different organs, sometimes forming compact masses of tissues, and at others running as slender and delicate isolated threads.

317. It has been seen in 201 that meristem is the nascent state of any tissue, and that it may multiply as such, or first become differentiated into elongated forms (cambium). For convenience of reference, the meristem at the growing-points of the axis of the plant is given special names: *Dermatogen*, the layer of nascent epidermis; *Periblem*, the layer of nascent cortex just beneath the epidermis; *Plerom*, the cylinder or shaft of nascent fascicles. The cells from which these primordial layers or masses of nascent tissues arise are known as *initial cells.*[1]



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The initial cells produce primordial layers or masses of tissues; by their further development the primordial layers or masses give rise to the early distinctive tissues of an organ. The tissues thus early formed constitute the *primary structure* of the plant.

318. In the further growth of an organ, especially in plants which are to live more than a single year, or which have a well-defined period of rest, remarkable changes may take place in its structure, especially by the introduction of new elements. Such changes are known as secondary, and give rise to the *secondary structure* of the organ. From the nature of the case, it is impossible to draw a sharp line between the primary and secondary structure; but the division is nevertheless useful in the examination of the minute anatomy of the plant.

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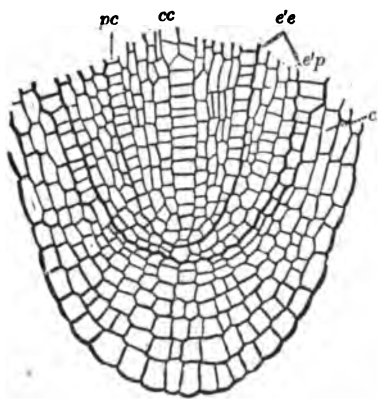
[1] Hanstein: Die Scheitelzellgruppe im Vegetationspunkt der Phanerogamen, 1868; also in Botanische Abhandlungen, 1871, p. 3.

The distinction between meristem proper and cambium is insisted on by Nägeli in his Beiträge (1858).

Fig. 84. Longitudinal section through the middle of the root-tip of the embryo of Pontederia cordata. The lower initial cells produce the cap, *c*; the middle, the nascent cortex, *ec*; the upper, the nascent central cylinder, *cc*. The nascent epidermis, *ep*, of the stem is continued down to the cap; *s*, the point to which the suspensor was attached. In other terms, *cc* is the plerom, *ec*, periblem, *ep*, dermatogen. (Flahault.)

THE ROOT.

PRIMARY STRUCTURE.



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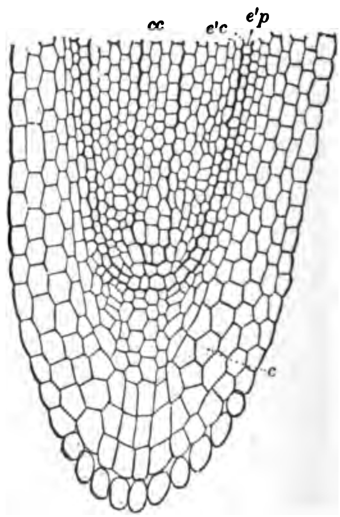
319. It was stated in Vol. I., p. 27, that the root, or descending axis, "normally begins in germination at the root-end of the caulicle, or so-called radicle; but that roots soon proceed, or may proceed, from other parts of the stem, when this is favorably situated for their production."

320. A longitudinal section through the tip of a germinating radicle exhibits only parenchyma cells. Slight differences exist between these cells, both as regards shape and size; at the very end of the radicle they are relatively large, and form a sort of cap-like covering (*root-cap*) for the smaller cells lying directly back (*the growing-point*). If the section is thin enough, it will be seen that at the growing-point numerous rows of cells appear to converge, the fact being that all the cells of such rows are derived by multiplication from those at the growing-point.



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321. Certain differences in the arrangement of these rows can be seen upon comparing the radicles of plants of different classes.

FIG. 85. Longitudinal section through the middle of the root-tip of Fagopyrum esculentum. The lower initial cells give rise to the cap *c*, and the epidermis *e'p*; the middle produce the cortex *e'e*; *pc*, peripheral layer of the central cylinder *cc*, which comes from the upper initial cells. (Janczewski.)

FIG. 86. Longitudinal section through the middle of a lateral root of Pontederia crassipes: *cc*, nascent central cylinder (plerom); *e'c*, nascent cortex (periblem); *e'p*, nascent epidermis (dermatogen); *c*, root-cap. (Flahault.)

Thus in most cases the group composing the point of growth consists of three kinds of superposed cells, so arranged in layers that each gives rise to a determinate portion of the forming root: (1) the outer or lower layer, to the root-cap and the rest of the *epidermis;* (2) the middle, to the cells which are immediately under the epidermis, — the *cortex;* (3) the inner or upper layer, to the *central cylinder*. But in some plants[1] there are more than three layers of initial cells (*e. g.*, Sparganium, Raphanus, etc.), while in others there are less than three (*e. g.*, only one in Cucurbitaceæ, two in Triticum).

322. **The Root-cap.** The growing-points of nascent roots originate just below the surface of the organ whence they proceed; hence roots are said to be formed endogenously. In emerging, they rupture the layer of tissue by which they had been covered, but are from the first protected at the end by a thicker or thinner mass of parenchyma, — the root-cap.[2]

323. It does not always have the same origin, as will be seen by the notes,[3] nor has it the same shape and size in all plants.

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[1] Janczewski (Ann. des Sc. nat., sér. 5, tome xx., 1874) describes six types of development of the tissues of the root: —

1. Four distinct layers of meristem; namely, Plerom, Periblem, Dermatogen, and Calyptrogen; *e. g.*, *Hydrocharis.*

2. A distinct Plerom and Calyptrogen, but the Periblem and Dermatogen have initial cells in common; *e. g.*, *Gramineæ.*

3. A distinct Plerom; the Periblem, Dermatogen, and Calyptrogen have common initial cells; *e. g.*, *Iridaceæ.*

4. A distinct Plerom and Periblem; the Dermatogen and Calyptrogen have common initial cells; *e. g.*, *Helianthus annuus.*

5. All four layers have common initial cells; *e. g.*, *Phaseolus* and *Pisum.*

6. Only a distinct Plerom and Periblem; therefore there is neither true epidermis nor root-cap, since these are formed simply by outer layers of the Periblem; *e. g.*, *Gymnospermæ.*

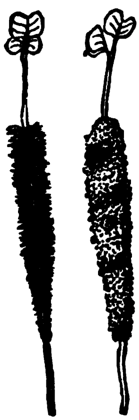
Treub (1876) and Eriksson (1878) distinguish seven types.

[2] According to Olivier, a part of the tissue thus broken through by the advancing radicle of grasses remains at its base, as the coleorhiza, while the rest becomes the root-cap (Ann. des Sc. nat., sér 6, tome xi., 1881, p. 19).

[3] According to Flahault (Recherches sur l'accroissement terminal de la racine chez les Phanérogames, Ann. des Sc. nat., sér. 6, tome vi., 1878), who bases his opinion on an examination of three hundred and fifty species of Phænogams, the terminal growth of the root may be referred to two structural types which are characteristic of monocotyledons and dicotyledons.

In monocotyledons the epidermis is generally formed by the initial cells of the cortex. The epidermis never gives rise to a root-cap; the root-cap once formed is continually renewed by the activity of its internal layers. In dicotyledons, on the other hand, the epidermis is almost always independent of the cortex; the root-cap is continually renewed by the activity of the cortex and epidermis.

Roots which grow in the earth seldom have it much developed; but in many aquatics it becomes of large size, though it is always thin. In some species of Pontederia the cap envelops the root for the length of half a centimeter; but it is free at its upper part, and is in contact with the root only at its very tip. The roots of Typhaceæ and Lemnaceæ exhibit nearly the same structure. The cap consists in these cases of only one or two layers of thin-walled cells.



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The aerial roots of some plants have large root-caps composed of firm-walled cells. This is well shown in Pandanus, where the cap consists of many layers of cutinized cells. The cap in all cases exfoliates on its exterior, and is as constantly renewed by the cells within. Nearly all of its cells contain starch-granules in abundance.

324. *The peripheral tissue* in the rootlet does not always have the same origin; it may in some cases be regarded as true epidermis, in others as the outermost portion of the cortical parenchyma. In the vast majority of cases this young superficial tissue is furnished with *root-hairs;* it is therefore designated the piliferous layer.[1]

325. **The piliferous layer** has no intercellular spaces (a few cases of aerial roots of Orchids excepted). The hairs are confined to a narrow zone a short distance behind the tip, although in Triglochin they have been found on the edges of the cap, and in Philodendron very near its edge. When first formed they have delicate transparent walls, and are filled with protoplasm. By the advance of the growing-point and with the formation of new hairs, the older become less active, their walls thicken and turn brown, their contents disappear, and they fall off, generally leaving a nearly glabrous surface.

326. The hairs are generally simple, but in the adventitious roots of some Bromeliaceæ[2] compound hairs are also found.

Branched hairs are seen on the roots of Saxifraga sarmentosa, Brassica Napus, etc.

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[1] Olivier (Ann. des Sc. nat., sér. 6, tome xi., 1881, p. 19), according to whom it is never homologous with the epidermis of the stem (p. 28).

[2] Jorgensen, Botanisk Tidsskrift, 1878, p. 144.

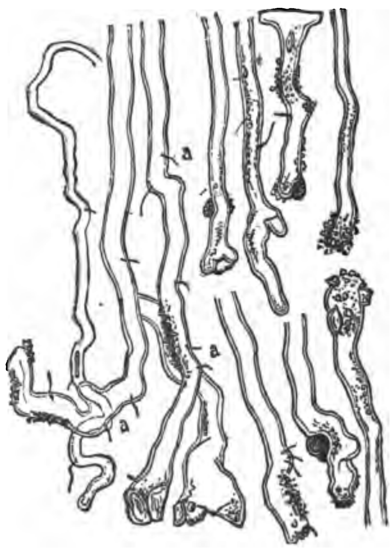
FIG. 87. Seedling of Sinapis alba, showing root-hairs.

FIG. 88. Seedling of same, showing the manner in which fine particles of earth cling to the root-hairs. (Sachs.)

327. Root-hairs are best obtained for study by cultivating seedlings on moist glass, or with the rootlets in water. It is well to compare the forms thus obtained with those found on roots of the same plant grown in loam, sand, fine clay, etc. Masters has shown that the development of the hairs is favored by many conditions, such as porosity of the soil, moisture, etc.; and this fact should be borne in mind in the examination of the root-hairs of any plant.

328. The walls of root-hairs are only slightly cutinized, but there is a great difference in this respect in different plants.

329. The cells of the superficial layer of the rootlet, other than those with hairs, are more or less cutinized, the degree of infiltration depending upon their age. In some cases (*e. g.*, Asphodelus) the thickening is very considerable.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330. On a few plants[1] no root-hairs have been detected, as Crocus sativus, Cicuta virosa, Abies pectinata and many other gymnosperms.

331. **Roots of orchids.** The newer parts of the aerial roots of Orchids have an epidermis consisting of nearly spherical tracheïds, which, except sometimes in the outermost layers, cohere without intercellular spaces. The walls of these cells are colorless, though in mass they may have a silvery lustre, and when immersed in water they soon become sufficiently transparent to permit the subjacent green tissue to be seen.[2]

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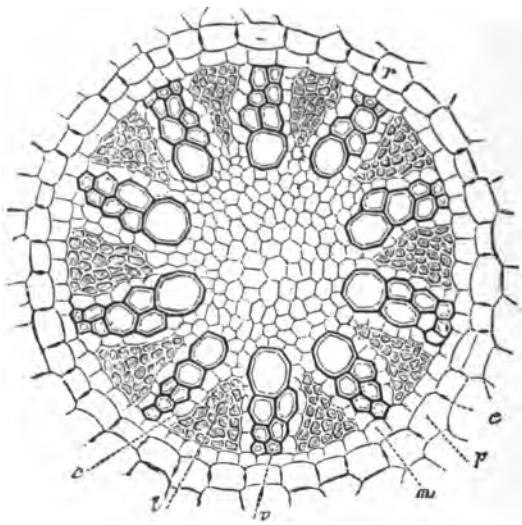
[1] Duchartre (Éléments de Botanique, 1867, p. 214) cites other plants. See also a valuable paper by Schwarz in Untersuchungen aus dem bot. Inst., Tübingen, 1882.

[2] According to Leitgeb, the old roots of Vanda furva are green because their tracheïds contain minute Algæ (De Bary, Vergl. Anat., p. 238).

FIG. 89. Root-hairs distorted by contact with the soil. Four in the right-hand upper corner, Selaginella; three in lower corner, Tritolium; the others, Avena. The dark points indicate the attached particle of soil. *a, a, a,* minute prolongations of the cell-wall. (Sachs.)

332. Sometimes there are papillar outgrowths from these tracheïds, which are to be regarded as root-hairs. They occur chiefly on younger parts of the roots which are in contact with a moist support, or which are kept wet. They cling tenaciously to moist surfaces, and may become much widened and flattened.[1]

333. The **cortex** of different plants varies greatly in thickness and compactness, and in the thickness of the cell-walls. In



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a few cases remarkable lacunæ are to be seen (*e. g.*, Menyanthes).

334. The cells bounding the inner layer of the cortex have the general characters described under "Endodermis;" their radial walls are generally more or less plicate, and there are no intercellular spaces.

335. In the primary cortex of roots all the various kinds of secreting cells and receptacles for exudations described on p. 92 may be looked for; but as a rule they are less developed than in the stem. Collenchyma occurs sometimes in roots; *e. g.*, Raphidophora.

336. The **central cylinder** has, at first, a peripheral layer of

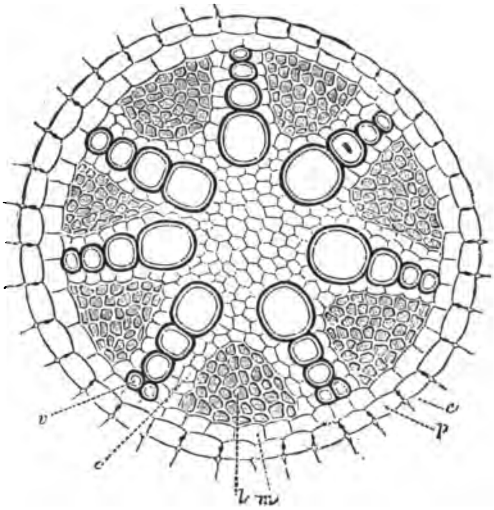
[1] Leitgeb: Die Luftwurzeln der Orchideen, Wien Akad. Denkschr., xxiv., 1865, p. 179.

FIG. 90. Transverse section of the central cylinder of a root of a vascular cryptogam (Marattia lævis): *e*, internal layer of the proper cortex; *p*, endodermis; *m*, peripheral layer of the cylinder; *l*, liber fascicles; *v*, woody fascicles; *c*, conjunctive parenchyma (pith and medullary rays). (Van Tieghem.)

thin-walled cells in close union with the endodermis; at certain points on this layer the woody and the liber fascicles appear, the latter alternating with the former throughout the circle, and the spaces between them being filled with parenchyma.

337. The number of fibro-vascular bundles in the central cylinder varies according to the class of plants, and in the same plant according to the age and size of the root. There are generally two in Cruciferæ, often three in Ervum Lens, four in Ricinus, five in Vicia Faba, six in Alnus, and eight in Fagus; but these numbers are by no means constant.

338. The woody part of the bundle may become re-



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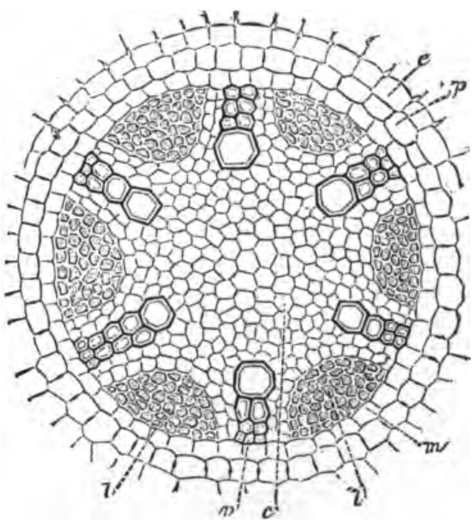

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FIG. 91. Transverse section of the central cylinder of a root of a monocotyledon (Colocasia antiquorum): *e*, internal layer of the proper cortex; *p*, endodermis; *m*, peripheral layer of the cylinder; *l*, liber fascicles; *v*, woody fascicles; *c*, conjunctive parenchyma (pith and medullary rays). (Van Tieghem.)

FIG. 92. Transverse section of the central cylinder of a root of a dicotyledon (Artanthe elongata): *e*, internal layer of the proper cortex; *p*, endodermis; *m*, peripheral layer of the cylinder; *l*, liber fascicles; *v*, woody fascicle; *c*, conjunctive parenchyma (pith and medullary rays). (Van Tieghem.)

duced to a single duct, as in some Carices, or there may be a large duct surrounded by smaller ones with or without intervening cells, or many large and small ducts variously conjoined. Moreover, there are all degrees of compactness in the union of the different bundles of woody tissue with each other.

339. The cribrose part of the bundle may be reduced to a single cribrose tube (*e.g.*, Anacharis), or two or three (*e. g.*, Pontederia); but usually there are many, which may be variously disposed.

340. Bast-fibres may be associated with the cribrose-cells in the primary structure of the root, and they may be scattered (and occasionally with some sclerotic parenchyma) in the cortex. In Philodendron these scattered groups of bast-fibres frequently contain oleo-resin canals.

SECONDARY STRUCTURE.

341. The older parts of roots, even the recently formed portions lying just back of the root-hairs, may undergo changes either by the alteration of their existing tissue elements or by the introduction of new elements. Some roots, however, do not suffer much change from first to last. Their cells may become more strongly cutinized or lignified as the case may be, but no new elements are brought in. This is true of the roots of many monocotyledons, but in dicotyledons the secondary changes are generally very marked. The changes may affect either the cortex or the central cylinder; in some cases the former more than the latter.

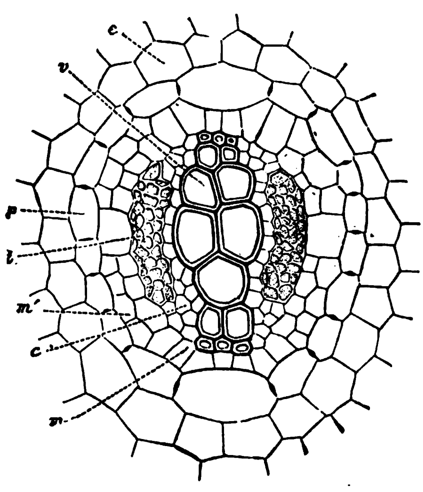

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FIG. 93. Section through the central cylinder of a binary root of a vascular cryptogam (Cyathea medullaris): *e*, internal layer of the proper cortex; *p*, endodermis; *m*, peripheral layer of the cylinder; *l*, liber fascicles; *v*, woody fascicle; *c*, conjunctive parenchyma (pith and medullary rays). (Van Tieghem.)

342. In the **cortex,** according to Olivier,[1] the secondary tissues are either parenchymatous or suberous (corky). The secondary parenchyma of the integument proceeds from the peripheral layer of the central cylinder. The suberous tissue in gymnosperms and in dicotyledons with caducous primary cortex is derived from the pericambial layer; it is composed of tabular cells with very short radial walls, and begins to form outside of the primary liber. In the case of woody dicotyledons with late-formed secondary vessels, and in monocotyledons, it is produced in the external zone of the cortical parenchyma, and is composed of cubical cells.

343. In a given species the level of the root where cork appears depends on the transverse diameter of the root, and also on the surroundings; in roots of the same size the cork generally appears earlier, and is more abundant in aerial than in earth roots.

The cortical parenchyma is renewed by layers of cells just outside of the sheath of the central cylinder, and its development is wholly centrifugal.

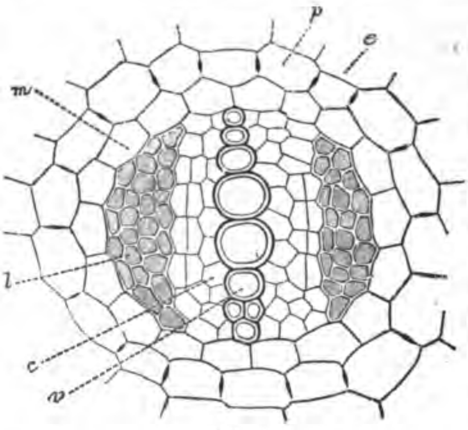
344. **The central cylinder** undergoes its most remarkable changes as the root grows older, in the group of dicotyledons. There is very little change, if any, in monocotyledons, but in a few of the latter some of the secondary changes now to be described can be observed (*e. g.*, Dracæna).

345. In dicotyledons, including gymnosperms, the thin-walled cells of the central cylinder are in contact with the inner face of the endodermis, and are known collectively as the *pericambium.* Touching this pericambium like the two ends of a bow, there runs a mass of delicate cells behind each liber bundle. At the point where these bows touch the inner face of the liber bundle a group of cells divides tangentially, forming a cambium layer, which soon gives rise within to new woody elements (often coalescent with those of the primary woody bundles), and on the outside to new liber elements. These new productions are called *secondary wood* and *liber.*

346. In some cases — for instance Pinus — the cells of the pericambium outside of the primary woody bundles produce new wood and new liber. The wood is in contact with the primary wood, while the liber may serve to connect the bundles of primary liber, thus bringing about a union more or less complete between similar elements. From these secondary pro-

[1] Annales des Sc. nat., sér 6, tome xi., 1881, p. 129.

ductions come, of course, the apparently unbroken rings of liber and the solid masses of wood in old roots. If this development of new wood and liber in a perennial dicotyledonous plant proceeds uninterruptedly, there will exist at the end of the first year secondary elements in large amount. After a period of rest, a perennial root resumes growth at the points where it was suspended, and the formation of new cork, cortex, liber, and wood goes on as before, until it receives further checks. Owing to conditions to be explained later, the character of the woody elements is not the same at the beginning and end of an active period; hence there is generally a clearly defined outline bounding the product of growth of successive years.



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347. More or less of the parenchyma of the original cylinder may remain in the form of radial lines or of bands (medullary rays), some of the same sort of tissue may be subsequently produced from new points of activity, and hence long and short radii will be met with.

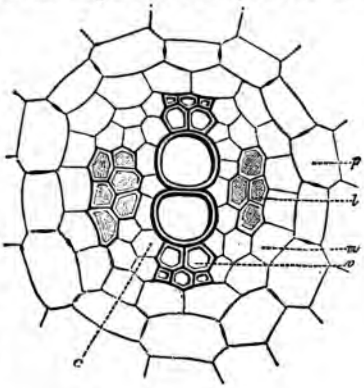

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FIG. 94. Section through the central cylinder of a binary root of a dicotyledon (Beta vulgaris): *e*, internal layer of the proper cortex; *p*, endodermis; *m*, peripheral layer of the cylinder; *l*, liber fascicles; *v*, woody fascicle; *c*, conjunctive parenchyma (pith and medullary rays.) (Van Tieghem.)

FIG. 95. Section through the central cylinder of a binary root of a monocotyledon (Allium Cepa): *e*, internal layer of the proper cortex; *p*, endodermis; *m*, peripheral layer of the cylinder; *l*, liber fascicles; *v*, woody fascicle; *c*, conjunctive parenchyma (pith and medullary rays). (Van Tieghem.)

348. The distinction of texture marking the periods of rest is not clear in the liber, though even here it may sometimes be detected. The cork of the root frequently exhibits such distinction, but never so clearly as does the cork of stems.

349. It is a familiar fact, that the fleshy roots of many plants — beets, and the like — exhibit in the first year from seed concentric rings, which resemble those found in perennials. This appearance is due, according to de Bary,[1] to the fact that at an early stage of development (when the root is only about half a millimeter thick) a new cambium zone is formed in the parenchyma on the outer part of the central cylinder, and this divides tangentially, extending therefore in a radial direction, producing woody and liber elements, and at the same time divides laterally, so that the whole constitutes a zone hardly broken by the rays. Soon a second zone is produced in like manner, and afterwards others. In all these cases the elements are usually not much lignified, but the whole mass remains succulent.

It happens sometimes that tertiary formations are produced in the root, bearing somewhat the same relation to the secondary as these do to the primary. Even formations of higher order are sometimes met with. But the elements of all of these are easily identified, and their mutual relations can generally be so clearly understood that they do not need special description. The following enumeration embraces the most important of these formations: tertiary cork and cortex; fibro-vascular bundles in secondary cortex; tertiary liber and wood in secondary wood. Such anomalies are more frequent in the stem.

350. Roots branch by the development of certain cells at the peripheral layer of the central cylinder, and just in front of the woody fascicles.[2]

The root branches only laterally in flowering plants; in the Lycopodiaceæ there appears to be terminal bifurcation, and here each branch shares with its fellow the tissue elements of the root from which they both come.

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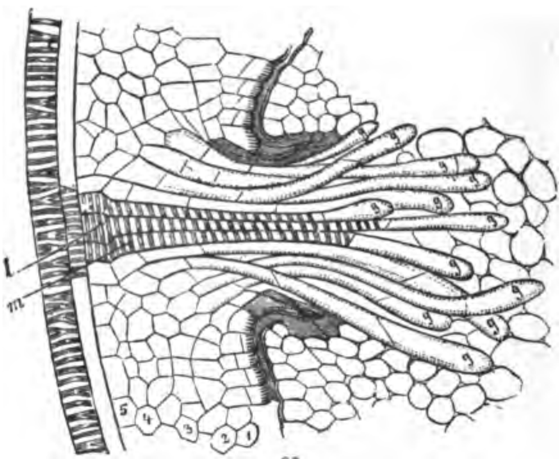
[1] Vergleichende Anatomie, p. 616.

[2] Three types of branching are described by Janczewski: 1. The mother-cells of this layer (the so-called Rhizogenic cells) most frequently give rise to all the tissues of the rootlet. 2. They produce only the central cylinder and cortex, but not the root-cap and piliferous layer, these being furnished by the endodermis of the root. 3. They produce only the central cylinder, the other tissues coming from the endodermis or from the layers immediately outside of it. The subsequent growth of the rootlet both in length and thickness is like that of the root.

351. **Parasitic roots,**[1] or those which fasten themselves for nourishment on other plants, are so much modified by the peculiar conditions under which they live, that they require special mention. Their structure can be best understood by a section through the root of Cuscuta.

Here there is no central cylinder, properly so called, nor is there anything answering to the root-cap. The cortex is regarded as reduced to a piliferous layer, since some of its cells are prolonged to form a fascicle of long hairs in intimate contact with the tissues of the host upon which it has fastened. In the centre of this fascicle of hairs some of the elements are tracheïd-like cells, which are in contact with ducts.



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352. The roots of many plants have distinctive colors: in some the color belongs to the wood (see 402); in others it is due to the cell-sap; in others, for instance, the common carrot, to orange-colored crystalline bodies. The crystalline forms found in the parenchyma of the roots of the carrot are minute rhombs, or sometimes rectangular plates to which starch-granules are attached. They are associated with small quantities of protoplasmic matter. (See Chapter IV., for an account of somewhat similar bodies occurring in flowers and fruits.)

353. **The roots of the higher Cryptogams** (such as Ferns and

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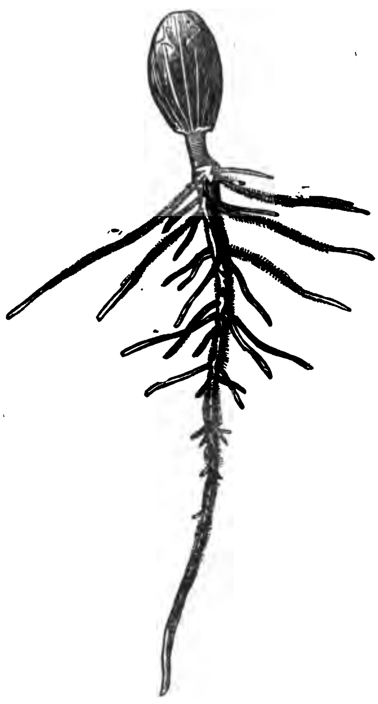
[1] An exhaustive paper on this subject will be found in Pringsheim's Jahrb., 1867: Ueber den Bau und die Entwicklung der Ernährungsorgane parasitischer Phanerogamen, von Hermann Grafen zu Solms-Laubach. Koch's paper is in Hanstein's botan. Abhandlungen, vol. ii., 1875.

Fig. 96. Vertical section of an haustorium of Cuscuta perforating the host-plant. *g*, *g*, absorbing hairs; the central cells are thickened at the base, where they are in contact with the ducts. (Koch.)

their allies) do not differ essentially from those of Phænogams; in most cases, however, the terminal growth, except in the order Lycopodiaceæ, is from a single apical cell instead of a group of cells. The apical cell produces not only the tissue of the body of the root as it extends in length, but gives rise also to the superficial cells at the extremity which constitute the root-cap. Lateral roots start from the interior layer of the cortical parenchyma, and not from the pericambium (see 345).

354. The fibro-vascular bundles are concentric (see 313), as indeed they are in the stems of most of these plants; that is, the bast part surrounds the wood part, as if with a sheath, even where the latter part is rudimentary. There is a tendency in the root, less marked than in the stem, to the production of sclerotic cells of a dark color.



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The roots of the higher cryptogams do not materially increase in thickness after they are first formed.

355. Proper roots are not found in Muscineæ (the mosses and hepatics); the absorbing organs here are more strictly root-hairs. These arise as papillæ from the outer cells, and speedily develop into tubular and frequently complex bodies. They often become branched in a remarkable manner, twisting and coiling around one another like the fibres in a thread. They, as well as the somewhat simpler organs of the same nature, found in the Thallophytes (such as Algæ, and the like), are termed *Rhizoids*.

FIG. 97. Seedling of Cucurbita Pepo, showing the main root, side roots, and root-hairs. (Sachs.)

Neither in Muscineæ nor Thallophytes are fibro-vascular bundles found, although in the former the arrangement of elongated cells sometimes resembles that of the constituents of a simple fascicle. The root-like bodies by which large sea-weeds cling to their supports are *hold-fasts*, rather than true roots; the whole surface of the plant being bathed in water, all parts can probably absorb equally well.

THE STEM.

356. That part of the axis of the embryo which is below the cotyledons is known as the radicle. It is more properly termed caulicle (that is, stemlet), for its mode of growth is not like that of the root, but like that of the stem above the cotyledons. The name *radicle* should be restricted to that which is the beginning of the root, namely, the free end of the caulicle. The caulicle is termed also the hypocotyledonary stem, or hypocotyl; while for the axis which is developed above the cotyledons, that is, from the plumule, the name epicotyledonary stem may be used. A large hypocotyl, which has begun to germinate, displays the structure of the stem to good advantage; but the initial cells and the nascent tissues of the stem must be sought at an earlier stage, for instance, in the plumule of a well-formed embryo, as that of Phaseolus or Faba. A vertical section through the plumule, made transparent by a clearing agent (see 24), shows that the cells have much the same arrangement as in the root-tip, except that no protective cap is present.

357. The outer layer has divisions only at right angles to the surface; it is continuous with the epidermis further back, and is easily recognizable as nascent epidermis (Dermatogen). Enclosed by this are layers which form an arch, the nascent cortex (Periblem). This encloses a mass of tissue from which the fascicular system is derived (Plerom). These tissues are essentially the same in character and development as the corresponding nascent tissues of the root.

358. As the tissue elements develop from these nascent tissues, the stem is produced; its structure is, however, generally complicated by the early formation of lateral appendages, — leaves in some of their modifications. Moreover, the tissues of the stem are continuous with the tissues of the leaves, and it is therefore necessary to take into account the mutual relations of these two organs. The problem becomes still further complicated, in a large number of cases, by the production of branches of some

kind, the tissues of which are of course intimately united with those of the main axis from which they are given off.[1]

PRIMARY STRUCTURE.

359. In the stem, or ascending axis, the distribution of tissue elements is similar to that in the descending axis, — the root. There is a more or less transient epidermis, a cortical substratum, and a central cylinder of some kind.

360. **The epidermis** of stems presents few peculiarities of structure beyond those already described in Chapter II. In most herbaceous plants it persists with little change, except in the matter of trichomes, throughout the life of the plant; but in most ligneous plants it is replaced, often early, by other protective tissues. Persistent epidermis is found in many woody and half-woody plants; for instance, Russelia juncea, Leycesteria formosa, and Ptelea trifoliata.

In Palms[2] "the epidermis exists in old age only in the cane-like and calamoid stems; in the rest it is more or less destroyed by the action of the weather. In Calamus it consists of a simple layer of minute cells elongated in the direction from without inward, and forms a stony, brittle, shining layer."

361. **The primary cortex**[3] consists essentially of parenchyma in which isolated cells of a peculiar character may often be found, such, for instance, as crystal cells, laticiferous cells, tannin cells, and the like (see 292); and its intercellular spaces sometimes serve as receptacles for the various exudations. The parenchyma cells generally contain more or less chlorophyll, and some starch.

362. Immediately beneath the epidermis, and not easily distinguished from multiple epidermis, is a portion of the cortex known as Hypoderma.[4] It is rarely sclerotic parenchyma, more

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[1] In the plumule and other buds all these parts exist potentially; and the sequence of their development can be successfully followed out by the employment of seeds in different stages of germination, or buds collected on successive days in spring and preserved at once in alcohol. In all cases care must be taken to have the date of collection of each specimen recorded in such a manner that no confusion can afterwards arise.

[2] Mohl: Ray Society, Reports and Papers in Botany. The Palm-stem, Henfrey's Translation, 1849, p. 14.

[3] Vesque (in Ann. des Sc. nat., sér. 6, tome ii., 1875, p. 82) gives a very full treatment of the subject.

[4] The word Hypoderma was introduced by Kraus (Pringsheim's Jahrb., 1865–66, p. 321), to designate the layer of colorless cells under the epidermis of leaves, "das Analogon des Rindencollenchyms." It has since been extended to apply to the external cortex just under the epidermis of stems.

frequently it is collenchyma. Excellent illustrations of the latter kind of hypoderma are furnished by most Malvaceæ and Labiatæ.

363. Schleiden[1] distinguished four types of external cortical layers in dicotyledonous stems: 1. That existing as a perfectly closed layer (penetrated in some cases only by small canals opening into stomata); as in most of the Cactacæ, Rosa, Begonia, etc. 2. That divided into many bundles, so that the green cortical parenchyma reaches the epidermis; *e. g.*, in Malvaceæ, Solanaceæ, etc. 3. That which may be quite distinctly recognized as a special layer, but still grading into parenchyma at the borders; *e. g.*, in Pyrus Malus, Hedera, Ficus, etc. 4. That more completely merging into cortical parenchyma, and therefore less distinct; *e. g.*, in Populus, Salix, Sambucus, etc. There are some plants in which it is not distinguishable; *e. g.*, in Cheiranthus, Mesembryanthemum, etc.

In Papaver and species of Thalictrum the cells of the cortex next to the epidermis have thin walls, while the zone next to the central cylinder may be sclerotic.

The inner boundary of the cortex of the stem is, as in the root, the endodermis. The thin-walled cells just within it form the peripheral layer of the central cylinder, or shaft.

364. Variations in the cortex consist chiefly in one of the following modifications: 1. Increase of its layers, sometimes to an extraordinary extent, and often accompanied, especially in water-plants, by the formation of large air-bearing intercellular spaces. The student should examine the peculiar structure of the cortex at the nodes, in these cases of spongy cortex. 2. It has been previously shown (215) that collenchyma is a common modification of cortical parenchyma. A variation in structure reaching the same end as collenchyma, namely, strengthening the stem, is found in a great number of plants; the cortical parenchyma, especially at the outer part, becoming conspicuously sclerotic, and the tissue very compact. 3. Fibres may occur in the cortex, either isolated or in small fascicles.

365. **The primary fibro-vascular bundles** of the stem are developed at definite points in the peripheral layer of the central cylinder. Their structural elements, wood and liber, vary as regards their relative amount, even in the same plant. A given bundle may and generally does change much during its course, interlacing here and there with other bundles, and giving off branches at different points.

[1] Principles of Scientific Botany, p. 240.

When corresponding bundles of plants of different groups are compared together, some diversities as regards the arrangement of the wood and liber elements are exhibited; but most of the cases can be referred without difficulty to the class of

366. *Collateral bundles* (see 313) of the ordinary type; namely, those having liber on the external aspect and wood on the internal aspect. In some cases, however, this order may be exactly reversed; *e.g.*, in the cortical fascicles of Calycanthaceæ. The wood-elements in collateral bundles are generally arranged in radial series; the inner ducts or their equivalents (tracheïds) being more slender and having more closely coiled spiral markings than those nearer the periphery of the bundle. The radial series may be in close contact, separated by very thin plates of parenchyma, or may have a large amount of this tissue between them. In dicotyledons, as a rule, the ducts at any given distance from the centre of the stem have a noticeable uniformity, so that a cross-section of the primary tissue shows a number of concentric circles of ducts of the same size. Sometimes, however, the ducts in a radial series may be reduced to one. In stems of monocotyledons there is less regularity in the arrangement of the wood-elements, but there is a substantial likeness in their structure in any group. They are generally in the form of a blunt wedge, the apex towards the centre of the stem, the space between the inclined sides of the wedge being mostly occupied by small ducts, wood-cells, and fibres.

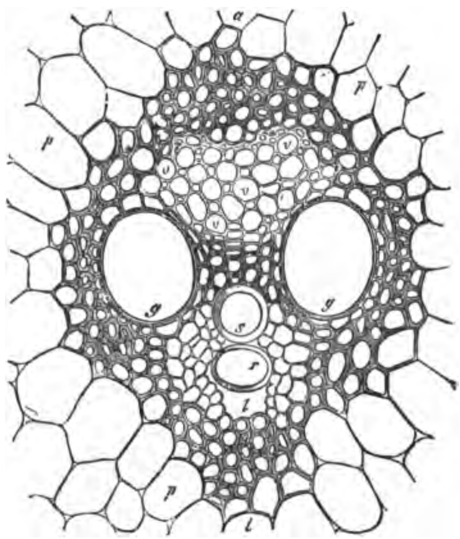

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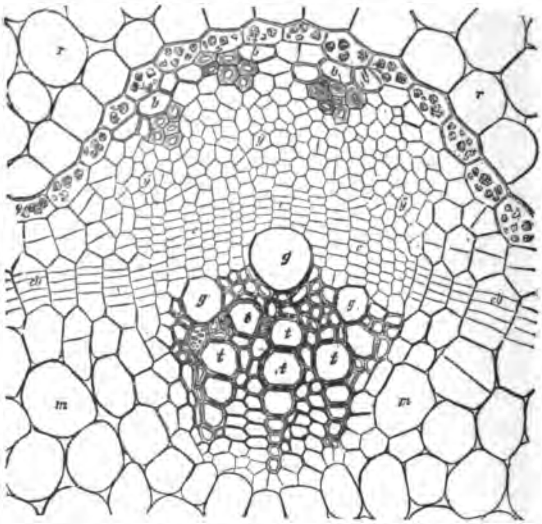
FIG. 98. Transverse section of a collateral fibro-vascular bundle of the stem of Indian corn: *p, p*, conjunctive parenchyma; *a*, outer face; *i*, inner face of the closed fibro-vascular bundle, which consists of a xylem portion (*g, g*, two large pitted ducts; *s*, spirally thickened duct; *r*, isolated ring of an annular duct; *l*, aeriferous lacuna, caused by splitting resulting from growth) and a phloëm portion, *v, v*. The whole bundle is surrounded by a bundle-sheath of thick-walled cells. (Sachs.)

367. The cribrose portion of a collateral bundle often has, in addition to true cribrose-cells, prismatic, thin-walled cells, known as *cambiform cells.*[1]

368. According to Vöchting[2] the cambiform and cribrose cells appear in some cases to have a common mother-cell, which divides obliquely in the direction of its length. The cambiform



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cells may divide by transverse partitions, and if the cells are moderately large the last divisions may be parenchymatous. In most monocotyledons and dicotyledons the cribrose-cells are much larger than the cambiform ones, and their cross-sections are distinguished by being less sharply quadrangular. In many succulents there are also very small cells resembling undeveloped cribrose-cells.

369. The cribrose and woody parts of a collateral bundle are generally distinguishable from each other by the lignified char-

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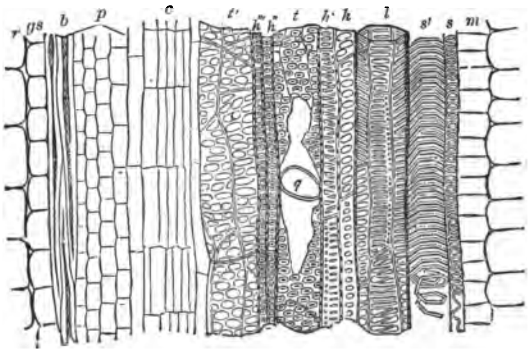
[1] De Bary reserves for these cells the term *Cambiform*, which was used by Nägeli in a wider sense.

[2] Beiträge zur Morphologie und Anatomie der Rhipsalideen, Pringsheim's Jahrb., 1874, p. 327.

FIG. 99. Transverse section of a part of the central cylinder of the mature hypocotyledonary portion of the stem of Ricinus communis: *r*, **parenchyma of the primary cortex;** *m*, **of the pith; between** *r* **and** *b* **is the simple endodermis containing starch-grains; the fibro-vascular bundle is made up of the phloëm** *b*, *y*, **the xylem** *g*, *t*, **and the cambium** *c*, *c*; *cb*, **interfascicular cambium. In the phloëm are the bast-fibres** *b*, *b*, **the soft bast** *y*, *y* **(partly parenchyma and partly cribrose-tubes); in the xylem, small pitted ducts** *t*, *t*, **wider pitted ducts** *g*, *g*, **and between them wood-fibres. (Sachs.)**

acter of the latter and the softer texture of the former. As has been before noticed (see 345), in dicotyledons and gymnosperms in which there is annual increase in diameter there is a layer of peculiar merismatic tissue (cambium) between the two parts. It is generally easy to identify the cells of this cambium layer, on account of their elongated form and intimate contact with each



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other. Their development gives rise (1) to new cells like themselves, (2) to cribrose and (3) to woody elements; all of which are to be examined later, under "Secondary Structure."

370. The sheaths of collateral bundles may have the character of typical endodermis and envelop the single bundles, or may consist of strands of long fibres (hard bast), which are on one side of the cribrose portion, and accompany the bundle through its whole course in the stem. The strands of fibres frequently encroach upon the cribrose part of the bundle so much as to be more or less commingled with it (see 311).

371. The stem may sometimes have *bicollateral* bundles either (1) with the woody part on the interior as well as on the exterior aspect (*e. g.*, Cucurbitaceæ), or (2) with an envelope of wood surrounding the liber; this envelope is seen at the extremities of the bundle, while the rest of it has the ordinary character (Iris).

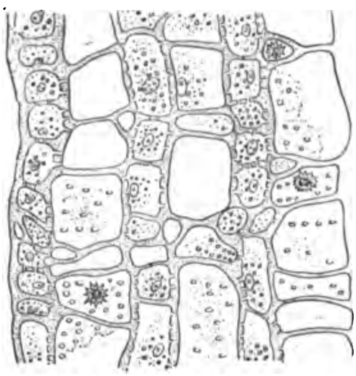
372. The bundles of the stem may be *concentric* (see 313); a

FIG. 100. Longitudinal section of a fibro-vascular bundle of Ricinus (the cross-section being shown in Fig. 99): *r*, cortical parenchyma; *gs*, bundle-sheath; *b*, bast-fibres; *p*, phloëm-parenchyma; *c*, cambium (the row of cells between *c* and *p* develops afterwards into a cribrose-tube); in the xylem portion of the bundle the elements are developed successively from *s* to *t'*; *s*, the first slender and long spiral duct; *s'*, wide spiral duct, the spiral band uncoiling; *l*, duct, thickened partly in a scalariform, partly in a reticulate manner; *h*, *h'*, *h''*, *h'''*, wood-cells; *t*, pitted duct; *q*. absorbed septum: *t'*, pitted duct, still young; in *l*, *t*, and *t'* the boundary lines of the adjoining cells which have been removed are shown in the wall of the ducts; *m*, parenchyma of the pith. (Sachs.)

ring of liber may surround the whole of the woody portion, or the wood may surround the liber. The former of these arrangements is common in the vascular cryptogams (see 354).

373. The pith of the stem consists of parenchyma frequently intermingled with other structural elements in small amount,[1] especially long fibres, woody prosenchyma, and latex-cells.

The parenchyma cells of pith have been classified in the following manner: (1) active cells, having the office of storing starch and other assimilated products for a time; (2) crystal-cells, in which crystals are formed; (3) inactive cells, which, having lost the power of receiving starch or other products, remain empty.



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These apparently unimportant distinctions have been shown by Gris[2] to be valuable in the identification of considerable groups of plants. Pith composed of active or inactive cells alone is termed by him homogeneous; that which contains more or less of both kinds of cells, heterogeneous. The arrangement of the elements in heterogeneous pith is so nearly constant as to have much interest for the systematist.

374. The medullary rays comprise the conjunctive parenchyma, which lies between the bundles in the stems of normal dicotyledons. The cells are for the most part much flattened radially, always so in those cases where the bundles are closely approximated (see also 207).

375. The stem develops from the bud by extension of its internodes. When these have attained a certain length, different

[1] The peculiar structures found occasionally in the periphery of the pith of Sambucus, and sometimes in the bark, have been mistaken for fungi, but have been shown by Oudemans and by Dippel to be receptacles for a very heterogeneous mixture of tannin and other matters (Verh. d. Nat. Vereins d. Preussens, Rheinlande und Westphalens, 1866, p. 1).

[2] A detailed account of the orders of plants examined by Gris will be found in Nouvelles archives du Muséum, t. vi. fasc. 3, 4, p. 201 (9 plates). An extract from the same is given in Ann. des Sc. nat., sér 5, tome xiv., 1872, p. 34.

FIG. 101. Clethra alnifolia. Longitudinal section through the reticulated pith of a young branch; each active cell contains a nucleus and chlorophyll grains, December. (Gris.)

for different stems, and depending often on some external conditions, they do not further elongate; but those tissues of the internodes by which growth in length has taken place become gradually firmer, and constitute permanent tissue. It sometimes happens that the nodes and internodes of the stem are not plainly distinguishable from each other. This is the case in most palms, where the growth takes place from the terminal bud alone.

376. Even a cursory examination of the structure of a stem which has thus unfolded from a bud shows that the number and the distribution of the bundles have much to do with the number and the arrangement of the leaves. Comparative investigations[1] of large orders of vascular plants have shown that the number of the bundles of the stem always bears some relation to that of the leaves at a given portion of the axis, and to the arrangement of the leaves. "The more bundles in a given leaf, and the greater the number of leaves in a cycle or whorl, the more numerous will be the bundles in the stem at that level. In monocotyledons with a large crown of leaves these two conditions are met with, and in these stems are found the greatest number of bundles."[2]

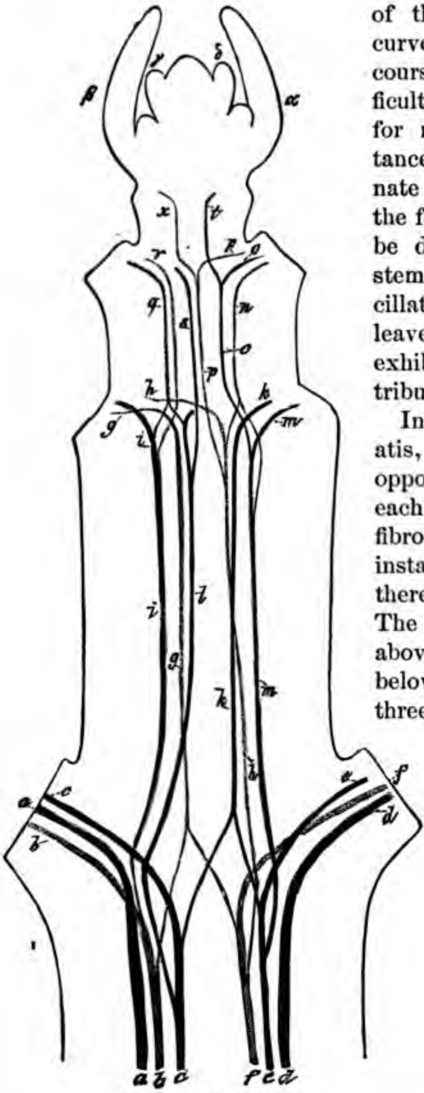
377. **Course and distribution of the bundles in the stem.** In the internodes, the bundles mostly run parallel to the axis, or in curves of very long radius; at the nodes, they may interlace transversely. If a bundle is followed through its course from below upwards, it will be found to branch at some of the nodes; the branch of the bundle going directly into the leaf at that point, or else passing upwards through other nodes until it reaches a leaf, the number of nodes traversed varying according to the kind of plant and the region of the stem.[3] More than one branch of the bundle may, however, go to a single leaf.

378. If, now, the course of the bundle be examined from above downwards, it can be seen that each leaf contributes its simple or compound fascicle to the larger bundle with which that from the leaf sooner or later becomes confluent. The fascicle from the leaf can frequently be followed down for several internodes as a separate thread, the so-called *foliar trace.* If such foliar traces are nearly isolated in their course, a cross-section of the stem will give a ground-plan of the leaf-arrangement. Usually, however, there is much complexity in the distribution

[1] Nägeli: Beiträge zur wissensch. Botanik, 1858, and Hanstein: Pringsheim's Jahrb., 1858.

[2] Van Tieghem; Traité de Botanique, 1884, p. 746.

[3] Van Tieghem: Traité de Botanique, 1884, p. 733.



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of the fascicles, and they curve considerably in their course, so that it is often difficult to follow the foliar trace for more than a short distance. If the stem has alternate leaves, the direction of the foliar traces will of course be different from that in a stem with opposite or verticillate arrangement of the leaves. The following figures exhibit the course and distribution in a few cases: —

In the leafy shoot of Clematis, Fig. 102, the leaves are opposite and decussate. From each leaf there descend three fibro-vascular bundles; for instance, at the lower node there are *a*, *b*, *c*, and *e*, *f*, *d*. The leaves at the node next above decussate with those below; each of them has three fibro-vascular bundles, respectively, *i*, *g*, *l*, and *k*, *h*, *m*, which become somewhat smaller as they descend to the next node, where they become blended with the bundles there. An examination of the third node shows that the two leaves there contribute bundles to the axial cylinder; there is again a blending of the bundles at the node below.

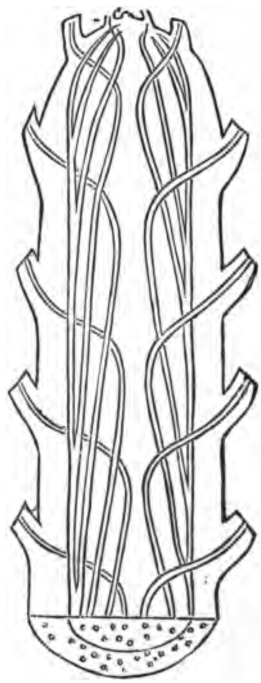
FIG. 102. Diagrammatic view of a leafy stem of Clematis, showing the arrangement of the fibro-vascular bundles: *a*, *b*, *c*, — *e*, *f*, *d*, the fascicles from the lower pair of leaves; *i*, *g*, *l*, — *k*, *h*, *m*, the fascicles from the second pair of leaves; *q*, *r*, *s*, — *p*, *n*, *o*, the

Both lateral strands of a leaf in such a case as this run down through one internode, bend outwards at the node below, and attach themselves to the lateral strands belonging there.

Suppose, now, that a cross-section of the stem of Clematis is made at the lowest node represented in Fig. 102; all the fibro-vascular bundles at that point will be seen in their relative positions, some of them cut squarely off, others obliquely, according to curves which they make. A cross-section in the internode above would show slenderer bundles, but all arranged in much the same manner as in the thicker internode below; that is, in a circle.[1]

The circle is made up of fibro-vascular bundles which have an inner portion of wood; within the circle is parenchyma (the pith), and outside of it more parenchyma (the cortex), which can be stripped off with the bast-portion of the central cylinder as bark.

Compare Fig. 102 with Fig. 103. In the latter, the stem does not exhibit in cross-section the fibro-vascular bundles arranged in a circle: they are more or less scattered; there is no clearly defined central portion nor well-marked outer portion free from them. Hence it cannot be said that such a stem has any distinction of pith, wood, and bark.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A further distinction may be here noted; namely, that the bundles in Fig. 102 have the power of increasing in thickness, adding new wood and new bast to the primary struc-

[1] Another feature must be attentively studied; namely, the relation of the forming bundles to the young leaves at the upper part of the stem. One may say the bundles descend from the leaf to the stem, or ascend from the stem to the leaf. But since the development of the leaf part and the stem part of a bundle goes on together, these terms, *ascend* and *descend*, should be understood to refer to our method of tracing the bundles out, and not to the method of their development.

fascicles from the third pair of leaves; x, t, fascicles of the fourth pair of leaves; β, α, — γ, δ, pairs of undeveloped leaves not as yet having fascicles. The diagram illustrates both Clematis Viticella and C. Vitalba. (Nägeli.)

FIG. 103. Longitudinal section through the stem of Aspidistra elatior, showing the curved course of the fibro-vascular bundles in the simplest palm-type. (Falkenberg.)

ture (see 390); but in Fig. 103 the bundles are *closed* (see 315), and incapable of further increase in thickness. Hence any further growth in thickness of the stem shown in Fig. 103 must be by the intercalation of new bundles.

379. It was held by Desfontaines [1] that the new vascular bundles in Palms originate in

[1] Quoted by Mohl, in The Structure of the Palm-Stem (The Ray Society, Reports and Papers on Botany; London, 1849).

Another illustration of the arrangement of fibro-vascular bundles is here given: —

The stem of the Vitis vinifera is usually regarded as sympodial; that is, it is composed of internodes belonging to different axes (see vol. i. pp. 54 and 154). In this species of grapevine two leaves in succession have a tendril on the opposite side, then follows a leaf without any tendril, next the sequence of two with

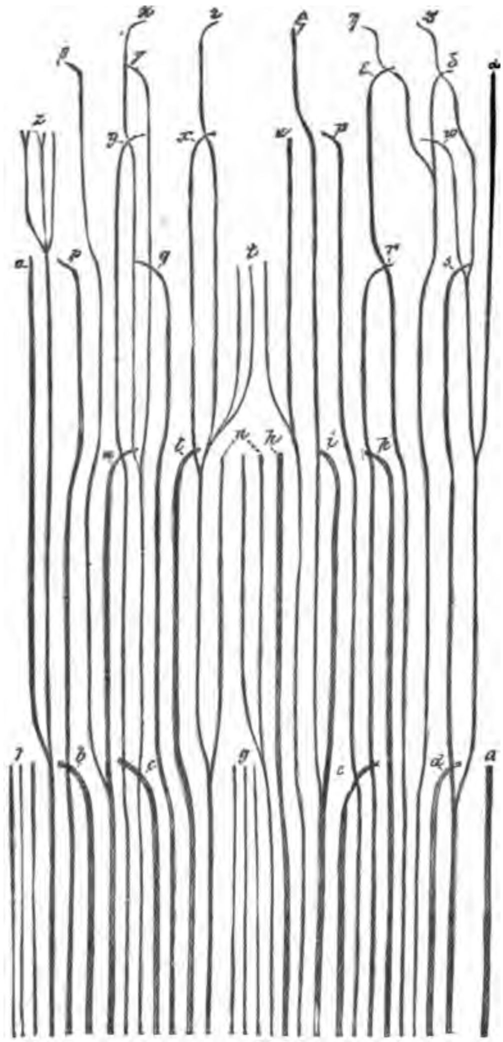

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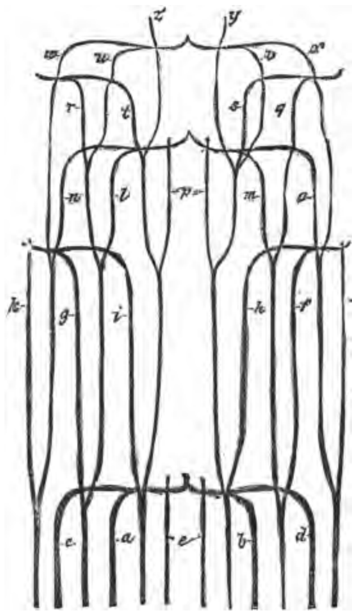
FIG. 104. Diagrammatic projection, showing the disposition of the fibro-vascular bundles in a leafy shoot of Vitis vinifera. Each leaf has five fascicles, which are unsymmetrically arranged: *a, b, c, d, e*; *h, i, k, l, m*; *o, p, q, r, s*; *u, v, w, x, y*; *α, β, γ, δ, ε*; *η, ζ, θ, ι, κ*. Each tendril has three fibro-vascular bundles passing in from the stem, *g, t, z*; the axillary buds have also three, *f* and *n*. (Nägeli.)

the centre of the stem, and that the hard and thick vascular bundles, situated at the periphery of the stem, are older than the softer ones occupying the centre. For stems like those of Palms he used the term *endogenous*, giving the name *exogenous* to the other class, in which new layers are added to the outside of the wood. The terms endogenous and exogenous were adopted by De Candolle, and have played an important part in Systematic Botany. Comparative researches have shown that the term endogenous as applied to the growth of stems like those of Palms is not appropriate, and hence the correlative words have been generally abandoned as names of the two great groups of plants. They are now generally replaced by the words monocotyledonous and dicotyledonous (see Vol. I. p. 69).

Moreover, it is now generally admitted that, although the distinctions pointed out in 366 — namely, those relating to the arrangement and course of the bundles — are valid for most plants of the two great groups, monocotyledons and dicotyledons, they do not hold for all.

380. Instead of describing the numerous exceptions to both of these groups *as* exceptions, many authors have endeavored to construct some new classification which shall embrace most of the anomalies in one or more co-ordinate divisions. Of these attempted



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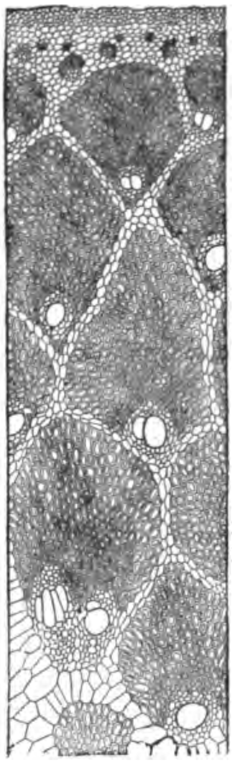
tendrils is resumed. Every leaf has five fibro-vascular bundles, which are arranged unsymmetrically, as shown in the figure. The long distance through which some bundles can run before uniting with any others, and the differences in structure at the successive nodes, are clearly exhibited in the diagram.

FIG. 105. Diagrammatic projection of the disposition of the fibro-vascular bundles in Phaseolus vulgaris. This diagram, like Fig. 104, superposes two longitudinal sections, both seen from the axis: *a, b, c, d; f, g, h, i; l, m, n, o; q, r, s, t; u, v, w, x;* the successive leaf-traces, each with four fascicles. Of the upper leaf-trace, the first two fascicles, *y, z*, are visible. *e, k, k, p*, fascicles for the three leaves below. (Nägeli.)

classifications only one will be given here, and that only in part and somewhat rearranged; namely, de Bary's: —

I. The palm-type. A cross-section of most monocotyledons shows that the bundles are not arranged in a simple ring, but that they are irregularly scattered or more or less crowded to form a shaft, which



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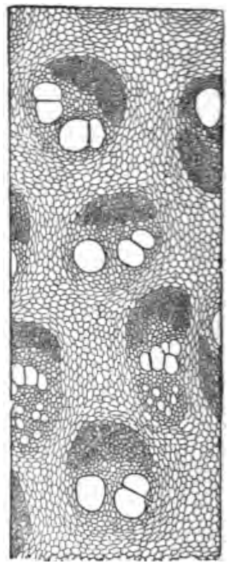

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may be hollow as in most grasses, or filled in the centre with parenchyma through which scattered bundles run. The periphery of this cylinder or shaft is not a true bark, nor is the middle a true pith. In the simple palm-type, all the bundles are leaf-strands.

II. The dicotyledonous type, in which all the primary bundles are leaf-trace threads. The bundles are arranged in a simple circle within which is pith, outside of which is cortex; medullary

FIG. 106. Transverse section through the outer part of the stem of Kunthia montana, a Palm. (Mohl.)

FIG. 107. Transverse section through the middle part of the stem of Corypha cerifera, a Palm. (Mohl.)

rays run between the parenchyma of the pith and that of the cortex. To this type belong most dicotyledons, Coniferæ, and Gnetaceæ (with the exception of Welwitschia[1]).

III. Anomalous dicotyledons, differing from the last in not having all their primary bundles arranged in a simple circle. The extra bundles may either be in the cortex, as in some Melastomaceæ and Rhipsalideæ, or they may lie in the pith either scattered or arranged in rings, as in Cucurbitaceæ, the herbaceous Berberidaceæ, species of Papaver, Thalictrum, Amarantus, and Phytolacca, many Nymphæaceæ, some Begoniaceæ, and a few species of Aralia.

De Bary's other classes comprise anomalous monocotyledons and certain higher cryptogams.

381. To make clearer the somewhat complicated structure of palm-stems which have unfortunately been selected in many text-books to illustrate the histology of monocotyledons, a few general statements are now given as introductory to the special treatment in the note.[2] That portion of a palm-stem which lies above the lowest active leaves (better called *fronds*) is of a conical shape, is often much elongated, and carries all the new and forming

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[1] For a description of this interesting plant, and an account of its peculiarities of structure, consult J. D. Hooker on Welwitschia.

[2] The exposition by de Bary of the structure of the simpler forms of Palms is given nearly in full in the translation which follows :—

"Since the appearance of Mohl's Palmenanatomie, the following main characters have been recognized as belonging to the simple palm-type.

"All the bundles in the cylinder (with some doubtful and certainly extremely insignificant exceptions which will be mentioned later) are leaf-traces. The base of the leaf includes the whole circumference of the stem, or at any rate the greater part of it. The leaf-trace is always several threaded : generally it consists of many threads, in stout stems even of a couple of hundred; its width is nearly the whole of the circumference of the stalk. From the base of the leaf the threads curve down into the cylinder, within which they descend, some in its outer surface and nearly radial and perpendicular, others radial and oblique, first pressing inward toward the long axis of the cylinder in a curve which is convex towards the upper and inner side of the stem, then curving outward, and gradually passing towards the outer surface of the cylinder, and in proportion as they approach this, approximating towards a perpendicular position. All threads descend through many internodes, and unite at last in the outer portions of the cylinder with others which enter it further down, attaching themselves to these in a direction which is sometimes tangential, sometimes radial, and sometimes oblique. Until this attachment of their lower ends, the bundles run independently. The union of the lower ends of bundles with others that enter the cylinder lower down generally takes place in such a way that the whole number of the bundles in successive internodes of equal circumference remains about the same. As the successive internodes and leaves

leaves. It is known as the *Phyllophore*. The newest leaves are formed nearest the apex of this cone; and here, as before shown, all the fibro-vascular bundles common to the leaves and stem originate. In most cases there is absolutely no increase in thickness of the stem below the base of this cone; but as the apex of the cone is developed and extends further upwards, thus elongating the stem, there is also a growth in thickness of the part of the cone just above its base. Thus a uniform size of the cylindrical stem is kept. But such increase in thickness cannot continue below the point at which there are active leaves.

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increase in size, the number of bundles grows larger, and conversely. The number of internodes through which a bundle passes cannot be fixed with exactness.

"Those bundles in a leaf-trace which curve like a bow towards the middle of a cylinder do not penetrate to equal depths; as a general thing, the median bundle of a series lies deepest, and the others lie less deep in proportion to their distance from this; the marginal ones descend nearly perpendicularly in the outer surface of the cylinder. Where there are several series of bundles, those in the inner series generally penetrate more deeply than those in the outer ones which lie at an equal distance from the median thread.

"The necessary consequences of the course described are: first, that in the cross-section of an internode the bundles stand closer together in proportion as they are nearer to the outer surface of the cylinder, — a phenomenon which is especially noticeable when the bundles are distributed over the whole surface of the cross-section of the cylinder; second, the successive traces dwindle, and their curving threads cross each other. Mohl's celebrated plan, which is here reproduced in Fig. 108, exhibits this latter relation in a radial longitudinal section, being based on the untenable assumption that all the threads of a trace are nearly equally curved, and are placed in a tangentially perpendicular direction, so that they form in the outer surface an open curving cone. If it

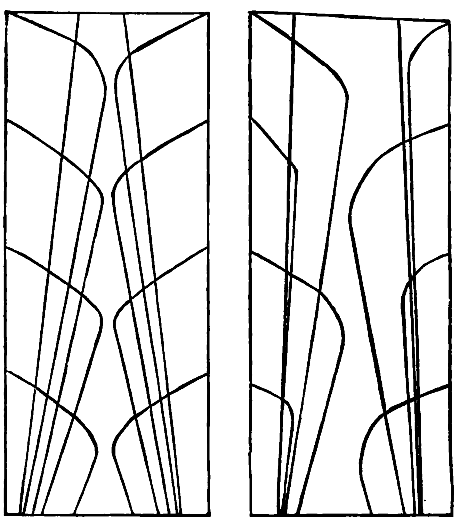

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FIG. 108. Mohl's diagram of the course of the fibro-vascular bundles.

FIG. 109. Diagram of the course of fibro-vascular bundles in a palm-stem with distichous leaves. (De Bary.)

382. Branner[1] has shown that the bundles in Palms do not end blindly at their lower extremities upon the surface of the stem, but that they are connected in sections or divisions from base to summit one with another, and one on top of another. He has further shown that each bundle lies in a spiral curve within which it grows; and whether it returns to the surface upon the side in which it originated or upon the opposite side, it is always in this curve.

383. The structure and development of monocotyledons have received much attention during the last few years, and the results obtained have caused some modification of previously existing classifications. Two of the proposed methods of re-arrangement are herewith given: —

384. Falkenberg recognizes the three following types of stems of monocotyledons.

I. The tissue of the central cylinder is not plainly separable even in its mature state into conjunctive parenchyma and fibro-vascular bundles. (To this type belong the water-plants, Zostera, Potamogeton, and probably all submerged monocotyledons.)

II. The bundles and the fundamental tissue are plainly differentiated; the former extending almost horizontally from the leaves to the middle of the cylinder, then curving downwards, running outwards, and finally terminating in the superficial

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is assumed that the leaves alternate with precisely one half divergence, and include the stem, and that the threads stand tangentially perpendicular, then the actual course in the stem will be shown in the plan of a radial section through the median thread of a leaf given in Fig. 109. But the assumption of a radially perpendicular course is valid only for those bundles which are also tangentially perpendicular. As was first observed by Meneghini, admitted afterwards by Mohl (Verm. Schriften, p. 160), and more minutely shown by Nägeli, each radially curving thread runs also in a tangentially oblique direction, and in spiral curves which are proportionate to the radial curving. Nägeli found the median thread of a leaf of Chamædorea elatior, Mart., for example, making 1½ revolutions in six internodes; in the sixth, it had not, in its outward course, quite reached the middle point between the centre of the stem and the inner surface of the bark. In stems with very short internodes and closely crowded bundles the spiral curves are at once perceptible in the cross-section, being plainest in the bundles of the stem of Xanthorrhoea, which press almost horizontally towards the centre of the stem, this peculiarity giving to its cross-section the strange appearance which has been frequently mentioned.

"Finally, many variations from that course of a thread which has here been described as typical may occur; there may be curvings alternately toward the outside and the inside, etc., which are not constant."

[1] Proceedings of American Philosophical Society, 1884, p. 459.

layers of the central cylinder. (The Mohl-Mirbel Palm-Type, illustrated by Asparagus, Iris, Canna, Aspidistra (see Fig. 103), Acorus, Scirpus, Zea, etc., the underground parts of Lilium, Tulipa, etc.).

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III. The bundles and the fundamental tissue are plainly differentiated; the bundles running downwards, and gradually converging at a point in the middle of the central cylinder, here blending with the leaf-traces of older leaves, without again curving outwards. (Examples are afforded by Tradescantia, the parts above ground of Lilium, Tulipa, etc.).

385. Guillard[1] describes six types of structure in the stems of monocotyledons which depend chiefly upon the relations of a central zone (called "intermediate") to the fibro-vascular bundles in the remaining portions of the stem. The classification has no substantial advantage over that of Falkenberg.

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[1] These types will be better understood after some peculiarities in the terminology are explained. By "pith," in monocotyledons, Guillard means the central region of parenchyma; by "intermediate zone," the active zone immediately surrounding the central region; by "cortical zone," the zone outside the external circle of bundles and the products of the intermediate zone. The six types are the following:—

1st Type. No intermediate zone between the pith and cortical zone; *e. g.*, Polygonatum vulgare.

2d Type. An intermediate zone represented by different tissues:—

1. Consisting of cauline bundles; *e. g.*, Iris florentina.
2. Consisting of meristemiform tissue (that is, tissue which produced from secondary meristem retains the shape but not the activity of meristem); *e. g.*, Chamædorea elatior.
3. Consisting of a fascicular sheath; *e. g.*, Epipactis palustris.
4. Consisting of the three foregoing; *e. g.*, Acorus Calamus.

3d Type. A single external zone of bundles, with a potential intermediate zone; *e. g.*, Luzula campestris.

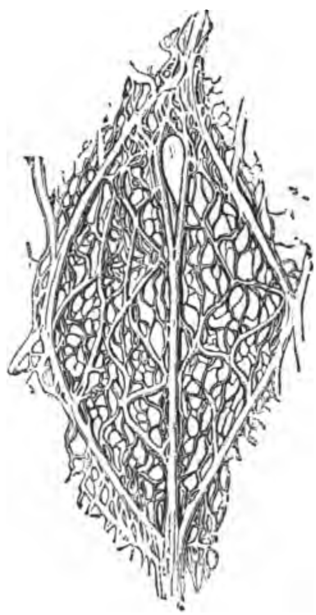
4th Type. Common bundles in two groups: one at the centre of the stem, the other forming the ordinary circle, separated from the first by a potential intermediate zone; *e. g.*, Tradescantia Virginica.

FIG. 110. Distribution of the fibro-vascular bundles in the leaf-shaped *branch* of Ruscus hypoglossum. (Ettingshausen.)

SECONDARY STRUCTURE.

386. It has been noticed that the fibro-vascular bundles of monocotyledons differ from those of dicotyledons chiefly in the possession by the latter of a layer of merismatic tissue (cambium) between the cribrose and woody portions. The stems of perennial dicotyledons increase in thickness from year to year chiefly by the annual production of a new mass of wood upon the inside of this layer, and of liber upon the outside; but the stems of most monocotyledons have no provision for annual increase in diameter. Hence it is convenient, in spite of numerous anomalies, to consider the secondary structure of the stem under these two heads.

387. **Secondary structure of monocotyledonous stems.** As has been already observed, the primary bundles in palms run from the leaves in curves of long radius until they again approach the surface of the stem, and their fullest development is found in the middle part of their course. While a cross-section exhibits these bundles as scattered without much order in a mass of parenchyma, a vertical section shows that they have entered the stem at different heights (since the leaves with which they were developed were at different points on the stem). A vertical section can display only parts of most of these curved bundles. At the stem of a palm just below the crown of leaves there are as many bundles seen in a cross-sec-



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5th Type. A central mass of secondary tissue, formed from central meristem. Intermediate zone well developed; *e. g.*, Triglochin maritimum.

6th Type. Bundles having several distinct liber elements; *e. g.*, Tamus communis. (Anatomie de la tige des Monocotylédones, Ann. des Sc. nat., sér. 6, tome v., 1878, p. 1.)

FIG. 111. A diamond-shaped mesh of primary fascicles intermingled with secondary fascicles in the stem of an Opuntia. (Reinke.)

tion as have been derived from the leaves at that point; and since these bundles do not possess a cambium layer, they have no power of increasing in size. The only changes therefore to be looked for in the stem of a palm from year to year are those in the ragged exterior from which the leaves fall, and the possible increase in firmness of the individual elements of the older bundles. The stems of most palms are as thick when they begin to ascend from the ground as they will afterwards be, their bundles early becoming permanent tissue throughout.

388. The presence of obscure nodes in the stem may complicate its structure somewhat by the introduction of horizontal interlacing bundles; but there is in these cases, as in the former, no provision for increase in thickness.

389. In some monocotyledonous stems new bundles can arise in a merismatic layer just within the cortex, and therefore cause an increase in the diameter of the stem.

A similar mode of increase in thickness is met with in the stems of many dicotyledons; as those of Nyctaginaceæ, many Chenopodiaceæ and Amarantaceæ, etc. Secondary bundles are formed in a merismatic layer outside the primary bundles, and in contact with their liber.

390. The **secondary structure of normal dicotyledonous stems** (see 369) is easily understood when it is remembered that the cambium of their primary bundles possesses the power of forming the following kinds of tissue: *a*, new wood on the outside of that which was last produced; *b*, a layer of new liber; *c*, fresh cambium for subsequent activity; and *d*, continuations of the medullary rays.

The cambium layer in the stems of most dicotyledons is composed of extremely delicate, thin-walled cells, which are filled with protoplasm and building materials. In the spring, when the bark is readily stripped from the wood, this layer appears to the naked eye as a thin film of mucilaginous matter having no cellular structure. In the case of such plants as the maple, birch, and pine, this juicy mass possesses a very sweet taste, owing to the large amount of organizable nutrient matter which it contains.

391. The cambium layer exposed by removal of the bark soon dies, and of course all further increase in diameter is impossible unless the wound is healed in some way (see 421).

392. The growth in size of the stems of normal dicotyledons depends therefore upon the existence and activity of cambium cells between the wood and bark. The juxtaposition of the

primary bundles brings the cambium into the form of a circle, sometimes broken, but frequently uninterrupted. If the cambium circle is substantially unbroken, a new compact ring of wood is laid upon the wood of the primary bundle, and a new ring of liber forms within the older liber. This action may be indefinitely repeated; and in a climate where there are notable differences either in temperature or moisture between the seasons, the concentric circles are records of the years.

If the primary bundles are not in contact, the new wood added year by year simply increases the size of the wedges at their outer part.

393. New bundles may be intercalated directly between those already present, and grow in much the same manner as the primary ones; or they may arise at new points of activity and produce great changes of form. In the same way tertiary changes and those of a higher order may follow the secondary ones, giving rise to stems which have a very complicated structure. The most puzzling

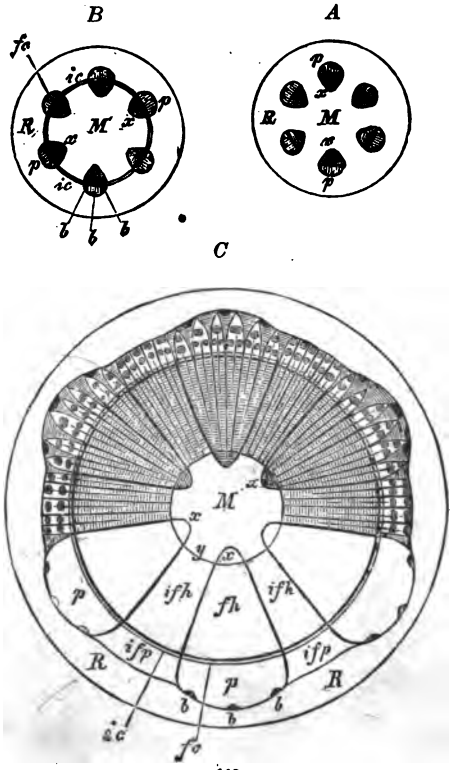

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FIG. 112. Diagrams showing the secondary increase in thickness of a normal dicotyledonous stem: *R*, cortex; *p*, phloëm with three fascicles of hard-bast fibres; *x*, xylem; *M*, pith. *A* shows only primary structure; *B* exhibits formation of the ring of cambium; *fc*, fascicular cambium; *ic*, inter-fascicular cambium; *b*, *b*, *b*, fascicles of hard bast; *C*, at the end of the year, after the formation of the secondary fibro-vascular ring; *p*, liber; *fh*, secondary wood of the bundle; *ifp*, inter-fascicular liber; *ifh*, inter-fascicular secondary wood; the entire ring is subdivided by medullary rays of different lengths. (Sachs.)

cases can generally be referred to eccentric growth of some one or more parts, as in flattened stems, or explained by the introduction and more vigorous growth of supernumerary bundles.

394. Extraordinary anomalies are afforded by the *lianes* of tropical countries, woody climbers with distorted stems. They belong chiefly to a few orders; namely, Bignoniaceæ, Malpighiaceæ, Menispermaceæ, and Aristolochiaceæ. A few interesting cases are shown in the accompanying figures, and are sufficiently explained in the descriptive letter-press.

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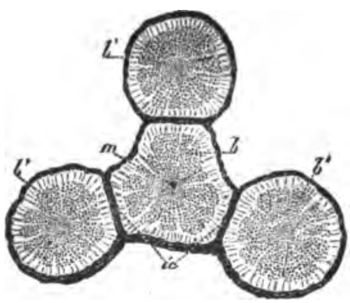

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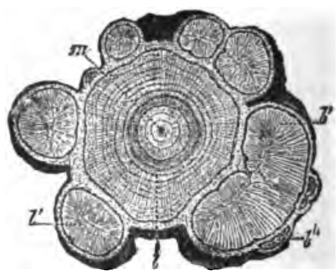

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395. **Spring wood and autumn wood.** The secondary wood annually produced in a temperate climate like ours exhibits certain differences between the inner and the outer portion of the year's

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FIG. 113. Transverse section of the stem of a liane belonging to the order Malpighiaceæ: *m*, pith; *b*, the central portion of the wood, arranged in concentric layers around the pith. (Duchartre.)

FIG. 114. Transverse section of the stem of a liane belonging to the order Malpighiaceæ: *m*, the pith. The bark follows all the irregularities of the wood. (Duchartre.)

FIG. 115. Transverse section of a liane belonging to the order Sapindaceæ: *b*, primary woody body having its own pith *m*, and bark *e′c*; *b′*, *b′*, *b′*, three secondary woody bodies without pith, but having as thick a bark as the primary body. (Duchartre.)

FIG. 116. Transverse section of the stem of a liane belonging to the order Sapindaceæ: *b*, the primary or central woody body having its own pith *m*; *b′*, *b′*, *b′*, *b′*, a circle of unequal secondary woody bodies; *b″*, tertiary woody bodies. (Duchartre.)

ring. That which is produced earliest (spring wood) has somewhat larger ducts and wood-cells than that which is formed later (autumn wood). The difference is not very striking when the wood of a single year is examined, for the diminution in size is gradual from within outwards; but if the autumn wood of one year is compared with the spring wood in the next ring, the difference is very marked. The cause of the difference in character between the early and later wood formed during a single season is supposed to be the greater pressure exerted by the tense bark in autumn. The experimental evidence in favor of this view will be presented in the chapter on "Growth."

396. In climates where there is no marked arrest of vegetative activity during the whole year, for instance, in that of the equatorial zone, the secondary wood seldom presents any clearly defined annual rings. In the wood of warm, temperate zones, however, well-marked annual rings are not uncommon.

397. It has long been known that in temperate climates a tree may exceptionally form a double ring in a single year. The cause of this in cases which have been carefully examined appears to be: (1) a partial cessation of activity owing to injury, followed by (2) a renewal of activity in the same season. Thus an elm may be stripped of its leaves in early summer and suffer a temporary check; but the buds already formed for another year develop into full leaf in a short time, the assimilative activity is resumed, and two rings are formed as a result of this cessation and renewal. Kny[1] has found this to be the case with several trees which had been deprived of their foliage at the end of June. Wilhelm has found by experiment that a tolerably well-defined double ring was formed in Quercus sessiliflora, from which he removed all the leaves on the 7th of June; while in a second case, where the foliage was removed later (July 10th), the duplication of the ring was not apparent.

398. From this statement it would appear that even in temperate climates, where there is a prolonged period of complete inactivity due to the cold, the number of rings shown in the cross-section of a stem may not exactly coincide with the number of years through which the tree has lived. But, as matter of fact, the lines of limitation in the intercalated rings are so much less distinct than those on either side, that the two lesser rings would be counted as one, and therefore be credited to the growth of one year instead of two.

[1] Verhandl. d. botan. Vereins der Prov., Brandenburg, 1880.

[2] Child: Popular Science Monthly, December, 1883.

The largest number of rings yet reported in any case appears to be that given for the great trees of California; namely, "2,100, with a probability that others considerably exceed this."[1] Other higher numbers of rings or estimates of age are, however, given in some works.[2]

399. That it is unsafe to base any calculation of the age of a tree upon its diameter follows from the fact that its growth during one year differs from that during another (see 400). Even the use of De Candolle's modification of Otto's rule,[3] which is perhaps the best yet given, leads to erroneous results. The method assumes that the number of rings averages nearly the same to any given unit of thickness in the outer as in the inner part of the stem. Having determined the number of rings in an inch just under the bark, this number is multiplied by the radius in order to obtain the whole. For example: Extract from opposite sides of a tree two pieces having a depth of two inches each. Suppose the number of rings in the two-inch piece on one side to be 20, while in the other there are 32, the average per inch will be 13. Deduct twice the thickness of the bark from the whole diameter of the tree, to obtain the diameter of the wood in inches, and multiply one half of the diameter by 13.

400. The woody rings annually formed in a stem differ considerably in size; a narrow ring being the growth of a cold

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[1] S. Watson, in Addendum to Botany of California.

[2] The following estimates cited by De Candolle (Physiologie Végétale, p. 1007) are believed to range altogether too high: —

The Linden of Neustadt, in Würtemberg, 1147 years.

The Oak of Bordza (on the Baltic), 710 distinct rings counted and 300 indistinct rings estimated = 1010 years. (By Otto's rule this would be 1080 years.)

The Yew of Crow-Hurst (Surrey), measured by Evelyn in 1660, 1458 years.

The Yew of Braburn (Kent), measured by Evelyn in 1660, and said by him to be *superannuated*, 2880 years.

The estimate given by De Candolle, of the age of trees of Adansonia (Baobab); namely, 6,000 years, has been shown by Dr. Gray (North American Review, 1844) to be wholly erroneous.

[3] Otto's rule is thus given by De Candolle: Ascertain the diameter at the height of about five feet, and make a notch at the same point on the circular surface, to count a certain number of annual layers which we measure. We then find the annual growth of those trees which have left off growing in height by the formula $\frac{4\,d\,(D-d)\,V}{n\,D^2}$, and of those which continue to grow in height by the formula $\frac{D^3-(D-2\,d)\,3\,V}{n\,D^3}$; D being the diameter of tree; V, volume of same; d, thickness of annual layers which have been counted; n, the number of these layers (Physiologie Végétale, p. 981 .

season, a broad ring of a warmer one. Their width varies also in the same species in different localities: thus, in Pinus sylvestris, grown between 50° and 60° north latitude, in Europe (the space occupied by the British Isles), the annual layers are very seldom less than $\frac{1}{3}$ of a millimeter in thickness; while in the same tree, grown far north, the thickness is not $\frac{1}{18}$ of a millimeter.[1] The width varies also in different parts of the same ring. For instance, in the case of Pinus sylvestris, Bravais and Martins found the two opposite radii in a stem to have the ratio of 9 to 19, the side having the greatest thickness being that which had its foliage best exposed to air and light. The eccentric growth of the wood of branches has been often noted; the longer radii are those on the lower side.

401. **Sap-wood** (Alburnum). The new and soft wood contains a larger proportion of soluble organic matters, of nitrogenous substances, and, when fresh, of water, than the older, harder wood lying just within. The " sap " of the tree is found in largest amount in the newer wood. The name *alburnum* was given to the sap-wood by the early histologists on account of its white or pale color. Contrasted with it, but not always very sharply, is the harder substance, **Heart-wood,** or Duramen.[2] The latter was given its name because of its greater hardness, or durability. Generally there is some distinction in color between the sap-wood and heart-wood, owing to the presence of peculiar coloring-matters lodged in the texture of the latter.[3]

402. **Color of wood.** The deep colors which characterize many kinds of wood are contained chiefly in the walls of the cells and ducts. In Hæmatoxylon Campechianum the coloring-matter sometimes occurs also in crystals inside the cells themselves or in clefts of the wood. The wood of Pterocarpus santalinus (Red Sanders-wood) consists of libriform cells intermingled with small groups of very large ducts, both of which contain the ruby coloring-matters in large amount. Many Berberidaceæ, Cladrastis tinctoria, Cercis, etc., have yellow coloring-matters in the wood; in Guaiacum the color is greenish; in black walnut, brown; in ebony, nearly black.

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[1] Bravais and Martins: Ann. des Sc. nat., sér, 2 tome xix., 1843, p. 129.

[2] The word *Duramen* is used by some writers to denote merely that heart-wood which has become very dense by peculiar infiltrations (Saunersdorfer, in Sitzungsber. d. k. Akad. Wien., 1882).

[3] The following figures, giving the proportion of sap-wood to the entire volume of the trunk, are from Tredgold (Principles of Carpentry, Section X., cited by Rankine): Chestnut, 0.1; Oak, 0.294; Scotch Fir, 0.418.

403. It may be here mentioned that many woods have characteristic odors; for instance, sandal-wood, violet-wood, and many of the coniferous woods.

404. The presence of resinous matters in wood, particularly when these are evenly although sparingly distributed through the mass, exerts a marked effect in retarding decay. The durability of the wood of Southern Cypress, even when exposed to the joint action of the warmth and moisture of a greenhouse, is usually attributed to their presence. But there are some cases of great resistance to the influences producing decay, which cannot be referred to the same mode of protection; for instance, those of Robinia Pseudacacia (or common "Locust") and Catalpa.

405. Various processes have been tried for destroying the putrescible matters in cells, or so modifying the character of the cell-wall that the wood can be protected against decay.

406. The oldest known method of preserving wood is carbonizing, or charring, by which those constituents of the wood specially liable to decay are so changed as to be no longer liable to putrefaction. The wood-preserving processes known as Burnettizing and Kyanizing have for their object the coagulation of protein matters in wood-cells, thus retarding if not preventing putrefaction.

407. In Kyanizing, a solution of mercuric chloride is forced into the texture of the wood; but the cost of this substance is so great, that it has led to a general abandonment of the process.

408. In Burnettizing, the wood is impregnated with a solution of zinc chloride containing about fifty-five per cent of the dry chloride. This is forced into the wood under pressure.

409. Another process — creosoting — depends upon the introduction into the wood of a solution of impure creosote, a pressure of about one hundred and fifty pounds to the square inch being maintained until the wood has absorbed a sufficient amount of the antiseptic liquid. Some of the antiseptic matters obtained by a rough distillation of coal-tar are also used for preserving wood.

It is an interesting fact that even wood which in the air is specially liable to decay can be preserved for a long time if deeply submerged in water.

410. There is an appreciable difference, especially in length, between the wood-cells of the earlier annual rings and those which succeed them; and Sanio has shown that an increase of length of the cells occurs up to a certain period of growth, when

an average appears to be established. This fact is illustrated by the following table, based on measurements of tracheïds of Pinus sylvestris.[1]

Number of the annual ring.	Medium length of the tracheïds.	Medium width of the tracheïds.
1	.95 mm.	.017 mm.
17	2.74 "	
19	3.13 "	
31	3.69 "	
37	3.87 "	
38	3.91 "	
39	4.00 "	
40	4.04 "	
43	4.09 "	
45	4.21 "	
46	4.21 "	
72	4.21 "	.032 mm.

From this table it is seen that the increase can be traced up to the forty-fifth year, but that from that time on, the tracheïds in one ring have the same length as those in the next. Those in the forty-fifth annual ring have an average length of about five times that of those in the first. In the wood of oak, the libriform cells exhibited the greatest difference in length. Thus Sanio found that in a stem of Quercus pedunculata, with 130 rings, the medium length of these elements in the ring of the first year was .42 mm., and in the three outer rings 1.22 mm. Tracheïds in the same rings measured, however, only .39 mm. and .72 mm. respectively. With this increment in the length of wood elements in successive rings, Haberlandt associates a fact noticed by Alexander Braun;[2] namely, that the wood elements in some stems and branches stand not parallel with the axis, but

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[1] Ueber die Grösse der Holzzellen bei der gemeinen Kiefer, Prings. Jahrb., viii. 409.

[2] Ueber den schiefen Verlauf der Holzfäser, und die dadurch bedingte Drehung der Bäume, Berlin, 1854.

It is proper to refer at this point to an instructive paper by Abromeit upon the histology of the oaks, in which the most marked characters of the North American species are fully treated (Pringsheim's Jahrb., 1884, p. 209). According to Abromeit, the oaks can be plainly classified as follows: —

I. With wide well-marked medullary rays.

A. The annual rings distinctly defined by the concentric circles of the larger ducts of the spring wood, and seen by the naked eye. The smaller ducts are arranged in radial rows in the autumn wood.

a. With thin-walled ducts.

α. The radial rows of small ducts touch each other tangentially: Quercus lyrata, alba, Durandii, stellata, macrocarpa, Wislizeni Prinus, Garryana, bicolor (var. Michauxii).

somewhat oblique thereto. The degree of obliquity is generally from 4° to 5°, but it is sometimes much higher than this; for instance, 10° to 20° in horse-chestnut, 30° in Syringa vulgaris (Lilac), 40° in Sorbus aucuparia, and 45° in Punica Granatum.

411. **Density of wood.** Owing to its greater firmness and smaller amount of putrescible substances, heart-wood is economically of far greater value than sap-wood; and hence nearly all determinations of density, strength, etc., are made upon it,

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β. The radial rows of the smaller ducts are relatively narrow and for the most part isolated tangentially: Quercus bicolor, sessiliflora, Iberica, grosseserrata, castaneifolia, pedunculata, Thomasii, undulata (var. grisea), Mongolica, macranthera, heterophylla.

γ. The radial rows of the smaller ducts are very narrow, and the ducts differ somewhat in width. The large ducts are in groups in the concentric circles: Quercus lobata.

b. With thick-walled ducts.

α. The large ducts in the concentric circles are indistinctly grouped, while the small ducts are crowded in narrow radial rows: Quercus rubra and the var. ? Texana. Quercus tinctoria.

β. Large ducts, as in the previous group. The radial lines of the smaller ducts wide, and the ducts themselves visible to the naked eye: Quercus imbricaria, hypoleuca, laurifolia, Kelloggii, palustris, falcata, Catesbæi, aquatica, nigra.

γ. With distinct radial grouping in the circles of the larger ducts of the spring wood. The radial rows of smaller ducts narrow and straight. The small ducts visible to the naked eye: Quercus Cerris, serrata, Phellos, coccinea.

B. Having thick-walled ducts of one kind, and these arranged in radial rows or groups. The annual rings are not distinct to the naked eye, and are defined chiefly by the thick-walled wood-cells of the outer layers of the autumn wood. They are easily made out under the microscope.

α. The radial rows of ducts are for the most part wide: Quercus virens, oblongifolia, chrysolepis, rugosa, Ilex, coccifera, Calliprinos, lanuginosa, paucilammellosa, glabra, Burgeri, gilva, thalassica.

β. Radial rows of ducts mostly narrow: Quercus Suber, agrifolia, glauca.

II. The wide medullary rays appear under the microscope to be somewhat interrupted by wood-cells, so as to appear like groups of narrower rays: Quercus dilatata.

The principal kinds of wood-cells in oaks, according to the nomenclature of Abromeit, are: first, the "pointed," of which there are two varieties, the septate and the unseptate; and, second, the "blunt," which are of comparatively wide caliber, and have thin walls. The length of the pointed cells in an average of 171 measurements was found to be 1.224 mm.; that of the blunt cells only .1 mm. Besides these two chief kinds, there are transitional forms of every sort.

rather than upon the latter. The lightest wood is probably the so-called "cork-wood" of the West Indies (Ochroma Lagopus), with a specific gravity of .25; the heaviest is Condalea ferrea, specific gravity 1.302.[1] The specific gravity of pure cellulose is given by authors variously as 1.25 to 1.52;[2] hence the figures noted above for the extremes of wood-density show indirectly the degree of buoyancy imparted by the air entangled in the tissues.[3]

412. Wood-fibre used for paper-pulp. The longer wood-cells of many common ligneous plants can be profitably separated

[1] Wiesner: Die Rohstoffe des Pflanzenreiches, 1873, p. 535.

[2] Ebermayer: Chemie der Pflanzen, 1882, p. 164. Husemann and Hilger: Die Pflanzenstoffe, 1882, p. 108.

[3] The following determinations were made under the direction of Professor C. S. Sargent, for the Tenth United States Census.

Botanical name.	Common name.	Region.	Av. sp. gr.	Wt. cu. ft. in lbs.
Sequoia gigantea.	Big Tree.	California.	0.3002	18.71
Pinus Strobus.	White Pine.	North Atlantic.	0.3842	23.94
Tsuga Canadensis.	Hemlock.	North Atlantic.	0.4202	26.18
Liriodendron Tulipifera.	Whitewood.	Atlantic.	0.4208	26.22
Taxodium distichum.	Cypress.	South Atlantic.	0.4438	27.66
Castanea vulgaris, var. Americana.	Chestnut.	Atlantic.	0.4504	28.07
Abies nigra.	Black Spruce.	North Atlantic.	0.4584	28.57
Populus grandidentata	Poplar.	North Atlantic.	0.4632	28.87
Pinus resinosa.	Norway Pine.	North Atlantic.	0.4854	30.25
Pinus rigida.	Pitch Pine.	Atlantic Coast.	0.4957	30.89
Acer dasycarpum.	Silver Maple.	Atlantic.	0.5269	32.83
Pyrus Americana.	Mountain-Ash.	Atlantic.	0.5451	33.97
Betula nigra.	Red Birch.	Atlantic.	0.5762	35.91
Platanus occidentalis.	Sycamore, Buttonwood	Atlantic.	0.6005	37.42
Juglans nigra.	Black Walnut.	Atlantic.	0.6143	38.28
Larix Americana.	Larch.	North Atlantic.	0.6236	38.86
Ulmus Americana.	White Elm.	Atlantic.	0.6516	40.61
Fraxinus Americana	White Ash.	Atlantic.	0.6530	40.70
Quercus rubra.	Red Oak.	Atlantic.	0.6612	41.21
Acer saccharinum.	Sugar Maple.	Atlantic.	0.6827	42.54
Fagus ferruginea.	Beech.	Atlantic.	0.6883	42.89
Quercus alba.	White Oak.	Atlantic.	0.7438	46.36
Betula lenta.	Cherry-Birch.	Atlantic.	0.7617	47.47
Quercus virens.	Live Oak.	South Atlantic.	0.9504	59.23
Guaiacum sanctum.	Lignum Vitæ.	Semi-tropical Florida.	1.1432	71.24

The specimens used in the above determinations by Mr. S. P. Sharples were dried at a temperature of 100° C. until they ceased to lose weight, when the specific gravities were obtained by measurement with micrometer calipers and calculation from the weights of the specimens.

For the purpose of utilizing histological features in the identification of woods, classificatory tables have been prepared by many authors. One of the most useful of these is given in Schacht's work, Die Pflanzenzelle, in which the different wood-cells of Coniferæ are described, in order to aid in the recognition of the genera. Another is de Bary's (Vergleichende Anatomie, p. 509,

from each other by mechanical or chemical means for use in the manufacture of paper-pulp. The woods which appear to have

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translated in Sachs's Text-book, 2d Eng. ed., p. 651), in which the structural characters of many kinds of wood are given. The table will be found convenient for reference.

1. Wood consisting only of tracheïds with bordered pits : —
   Wintereæ (Drimys Winteri, Tasmannia aromatica ; also Trochodendron aralioides) : (Conifers).
2. Wood consisting of vessels, tracheïds, parenchyma, and intermediate cells ; that is, substitute or replacing cells or fibres (ersatzfasern) : —
   a. With no intermediate cells ; Ilex aquifolium, Staphylea pinnata, Rosa canina, Cratægus monogyna, Pyrus communis, Spiræa opulifolia, Camellia, etc.
   b. With no parenchyma ; Porlieria.
   c. With both parenchyma and intermediate cells; Jasminum revolutum, Kerria, Potentilla fruticosa, Casuarina equisetifolia and torulosa, Aristolochia Sipho, etc.
3. Wood consisting of vessels, tracheïds, fibres, parenchyma, and intermediate cells : —
   a. With no intermediate cells ; fibres unseptate ; *e. g.*, Sambucus nigra and racemosa, Acer platanoides, Pseudoplatanus, and campestris.
   b. With both parenchyma and intermediate cells ; fibres unseptate ; Berberis vulgaris, Mahonia ; (Ephedra).
   c. With no intermediate cells; fibres septate and unseptate ; Punica, Euonymus latifolius and Europæus, Celastrus scandens, Vitis vinifera, Fuchsia globosa, Centradenia grandifolia, Hedera Helix, etc.
   d. With all four kinds of cells ; Mühlenbeckia complexa, Ficus.
4. Wood consisting of vessels, tracheïds, fibres, parenchyma, and intermediate cells. This is the most common, and may be taken as the typical structure:
   a. With no intermediate cells ; Sparmannia Africana, Calycanthus, Rhamnus catharticus, Ribes rubrum, Quercus, Castanea, Carpinus sp., Amygdaleæ, Melaleuca, Callistemon sp., etc.
   b. With no parenchyma ; Caragana arborescens.
   c. With both kinds of cells ; most foliage-trees and shrubs ; *e. g.*, Salix, Populus sp., Liriodendron, Magnolia acuminata, Alnus glutinosa, Betula alba, Juglans regia, Nerium, Tilia, Hakea suaveolens, Ailanthus, Robinia, Gleditschia sp., Ulex Europæus, etc.
5. Wood consisting of vessels, fibres, parenchyma, and intermediate cells : —
   a. With no parenchyma ; Viscum album.
   b. With no intermediate cells ; Avicennia.
   c. With both kinds of cells ; Fraxinus excelsior, Ornus, Citrus medica, Platanus, etc.
6. Wood consisting of vessels, fibres, and parenchyma : —
   Cheiranthus Cheiri, Begonia. Also many Crassulaceæ and Caryophyllaceæ.
7. Wood consisting of vessels, fibres, parenchyma, and true woody-fibres : —
   Coleus Macraei, Eugenia australis, Hydrangea hortensis.
8. Wood consisting of vessels, tracheïds, woody fibres, septate fibres, parenchyma, and intermediate cells : —
   Ceratonia siliqua, Bignonia capreolata ; it is, however, still doubtful if true woody-fibres are present.

been most extensively employed up to the present time are some of the species of Abies, Betula, Populus, Tilia, and Liriodendron Tulipifera (in the United States sometimes called "Poplar"). The chemical processes depend (1) upon the solvent power of caustic soda under pressure, and with heat, upon the so-called intercellular substance which unites the cells, or (2) upon the similar power of a sulphite, preferably magnesic, also under pressure and with heat.

413. **Bark. A, Secondary liber.** Each yearly addition to the inner surface of the bark is seldom plainly distinguishable from those which have preceded it, and hence we cannot determine positively the age of an old tree by the layers of its inner bark. The bast-fibres of a single year often cling together in a striking manner, forming bands or strips of considerable strength, and in a few cases, notably that of Daphne Lagetta, there are fine meshes between the fibres, so that the inner bark seems to be composed of layers of delicate lace.

A piece of thick bark of linden macerated for a while in water becomes so softened that the younger portion of the inner bark can be easily separated into the annual layers. Strips of the coherent fibres form the Russia matting of commerce. The strips often measure 2 – 3 meters in length, 2 – 5 cm. in width, and .04 – .08 mm. in thickness. Scattered among the individual hard-bast fibres there are many parenchyma cells, some of which plainly belong to the medullary rays, and others to the fibro-vascular bundles.

414. The bast-fibres, in a few instances, instead of being retained upon the stem for an indefinite period, are separated early, leaving the newer bast exposed. This is the case with some of our species of Vitis, in which the bast becomes detached in the form of long, loose shreds after the first year.

415. The crystals found in bast are very abundant. They are chiefly monoclinic, and occur both singly — arranged in rows — and in clusters.[1]

416. The appearance and distribution of the fibres of bast

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[1] De Bary gives the following list, taken chiefly from Sanio: —

Clusters of crystals in bast of Juglans regia, Rhus typhina, Viburnum Oxycoccus, V. Lantana, Prunus Padus, Punica Granatum, Ptelea trifoliata, Ribes nigrum, Lonicera Tatarica.

Single monoclinic crystals in bast of species of Acer, and the Pomaceæ, Robinia, Cladrastis, Ulmus campestris, Berberis, etc.

Single monoclinic crystals and clusters in bast of Quercus, Celtis, Æsculus Hippocastanum, Hamamelis Virginica, Morus, Salix, Fagus, Populus, Carpinus, Betula, Tilia, etc.

are so characteristic in certain kinds of bark that they may be used for identification. An example is given below.[1]

417. **B, Cork,** which has already been described in part in Chapter II., plays a very important part in the structure of older bark. Its relations to the cells which produce it, and to the epidermis which it displaces at an early period of its growth, will be plain from an examination of Fig. 117. In its production there are periodic arrests of activity just as in the case of wood, and hence in cork-tissue of firm texture it is possible to detect the lines of annual demarcation. When the cork of the cork-oak has reached a merchantable thickness (usually in ten to fifteen years), it is removed down to the phellogen, or cork cambium, and from this tissue new growths begin.[2]

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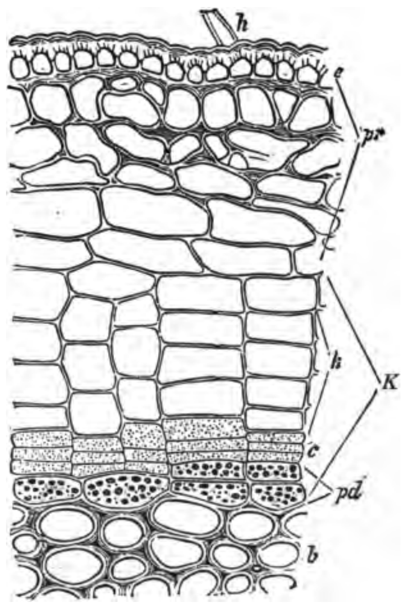
[1] "The liber is traversed by medullary rays, which in cinchona are mostly very obvious, and project more or less distinctly into the middle cortical tissue. The liber is separated by the medullary rays into wedges, which are constituted of a parenchymatous part, and of yellow or orange fibres. The number, color, shape, and size, but chiefly the arrangement of these fibres, confer a certain character common to all the barks of the group under consideration.

"The liber-fibres are elongated and bluntly pointed at their ends, but never branched, mostly spindle-shaped, straight, or slightly curved, and not exceeding in length 3 mm. They are consequently of a simpler structure than the analogous cells of most other officinal barks. They are about $\frac{1}{4}$ to $\frac{1}{8}$ mm. thick, their transverse section exhibiting a quadrangular rather than a circular outline. Their walls are strongly thickened by numerous secondary deposits, the cavity being reduced to a narrow cleft, a structure which explains the brittleness of the fibres. The liber-fibres are either irregularly scattered in the liber-rays, or they form radial lines transversely intersected by narrow strips of parenchyma, or they are densely packed in short bundles. It is a peculiarity of cinchona barks that these bundles consist always of a few fibres (three to five or seven), whereas in many other barks (as cinnamon) analogous bundles are made up of a large number of fibres. Barks provided with long bundles of the latter kind acquire therefrom a very fibrous fracture, whilst cinchona barks, from their short and simple fibres, exhibit a short fracture. It is rather granular in Calisaya bark, in which the fibres are almost isolated by parenchymatous tissue. In the bark of C. scrobiculata a somewhat short fibrous fracture is due to the arrangement of the fibres in radial rows. In C. pubescens the fibres are in short bundles, and produce a rather woody fracture" (Flückiger and Hanbury, Pharmacographia, p. 317).

[2] As noticed in 246, the inner layer of cork-meristem may give rise to parenchyma cells containing chlorophyll. Of these cells Sanio says: "They never become cork-cells, but are truly parenchymatous; they are filled with chlorophyll, starch, and sometimes with crystals. They never become lignified, but the wall remains as unchanged cellulose, and, in short, they are true cortical cells. Since, then, they owe their origin to the activity of the cork-meristem, but behave throughout their whole subsequent development precisely like the cells of the cortex, they may be called cork-cortex cells. When they form a distinctly defined layer, the term Phelloderm is appropriate" (Pringsheim's Jahrb., 1860, p. 47).

418. In some plants, notably the birch, papery layers exfoliate from time to time, while in some other plants, *e. g.*, the shag-bark hickory, large strips of irregular form and thickness are detached. Owing to the mode of their formation, such separated pieces may contain very heterogeneous elements. Of them Sachs says:[1] "Not unfrequently the formation of cork penetrates much deeper [than the periderm]: lamellæ of cork arise deep within the stem as it increases in thickness; parts of the fundamental tissue and of the fibro-vascular bundles, or of the tissue which afterwards proceeds from them, become, as it were, cut out by lamellæ of cork. Since everything which lies outside such a structure dies and dries up, a peripheral layer of dried tissue collects, which is very various in its form and origin. This structure, abundant in Coniferæ and in many dicotyledonous trees, is the *bark*, the most complicated epidermal structure in the vegetable kingdom."



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419. **Injuries of the stem.** The stem, especially in the case of plants living many years, is particularly liable to injuries, the most frequent of which are of course the wounds left by the falling of the lower limbs. It is proper to treat here of the natural repair of such injuries.

420. When any part of a plant suffers serious mechanical injury by which the deeper tissues are exposed, the surface of

[1] Text-book, 2d Eng. ed., 1882, p. 95.

FIG. 117. Formation of cork in a branch of Ribes nigrum, one year old; part of a transverse section; *e*, epidermis; *h*, hair; *b*, bast-cells; *pr*, cortical parenchyma distorted by the increase in the thickness of the branch; *K*, total product of the phellogen *c*; *k*, the cork-cells radially in rows, formed from *c* in centrifugal order; *pd*, phelloderm (parenchyma containing chlorophyll formed centripetally from *c*). (Sachs.)

the wound exhales moisture very rapidly, and under ordinary circumstances, except in spring, soon becomes dry. As Hartig[1] has shown, the drying of the exposed tissues is fatal to their component cells, and the organic contents speedily undergo chemical decomposition. The products of this decomposition have been further shown by him to be fatal to neighboring cells, and under certain conditions the mischief may progress to an irreparable extent. But usually there is an arrest of the destructive action either from lack of the free oxygen necessary for the putrefactive process, or by the protection afforded by tissues for repair. Wounds in resinous trees are measurably hindered from effecting much damage, owing to the exudation of liquid resins which exclude air.

421. The smaller wounds of a plant are generally healed by cork or by callus. 1. By cork. The superficial layer of cells at the surface of the wound is destroyed by the injury, and dries at once. In soft tissues the layer just below this immediately becomes merismatic, and behaves precisely like normal cork-meristem, covering the entire wound with a grayish or brownish film, which is in unbroken connection with the edges of the wound. Extreme dryness of the air, or, on the other hand, extreme humidity, hinders repair by cork. 2. By callus. This is best studied in leaves and in "cuttings." When a young, juicy leaf is wounded by an incision, some of the cells at the exposed surface may give rise to elongated sac-like bodies, which fill up the greater part of the injured cavity, and, according to Frank,[2] serve as a new epidermis. Or small cells in close apposition may be at once formed, and completely protect the tissue below. In "cuttings" the callus immediately forms a swelling near the wound. A portion of the callus may by continued cell-division extend over the cut end, everywhere bounded on its exposed surface by a cork layer. Activity of the cells in the callus and around the fibro-vascular bundles soon gives rise to new parts, for instance, roots.

422. It often happens under favorable conditions that a large mass[3] of tissue is gradually formed around, and finally over, a large injured surface.

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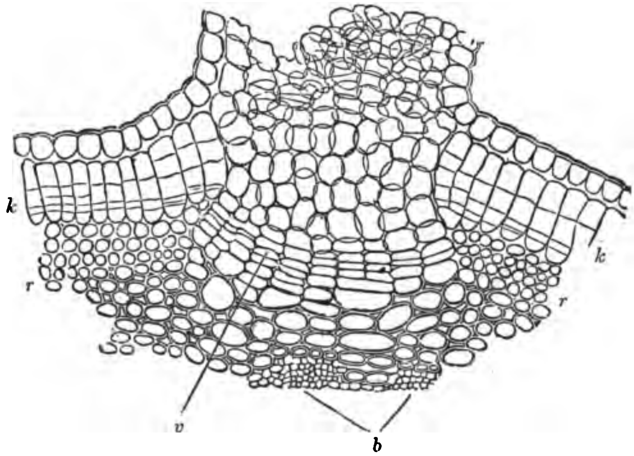
[1] Zersetzungserscheinungen des Holzes, Berlin, 1878. (Quoted by Frank.)

[2] Die Pflanzenkrankheiten, 1879.

[3] Usually when a branch dies it remains attached for a while to the stem; and no wound is in fact caused until the slow desiccation of the deeper tissues has gone on to a considerable extent, and without exposure to atmospheric air or outside moisture. When the branch at last falls off, the tissues around

423. **Lenticels** are peculiar breaks in the continuity of the periderm of dicotyledons. In some cases they can be detected under minute elevations of the epidermis of the first year, which split open either at the end of that season or during the next, forming a rift running lengthwise of the stem. Through this cleft



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underlying tissues appear, protruding in an irregular manner, the whole structure constituting a lenticel. According to Stahl,[1] there are two types of lenticels: 1. Those with loose cells in the rift, alternating with denser lines of cells. This is the most common type, good examples being afforded by Alnus, Prunus, Æsculus, etc. 2. Those with closely united cells and with no alternating denser lines. Illustrations can be found in Sambucus (see Fig. 118), Salix, Cornus, etc. The same authority states that in winter both of these kinds form an impervious periderm-like layer. It appears from Stahl's examination that in their complete and open state they aid in the exchange of gases between the interior and exterior of the stem. Klebahn[2]

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its base are in a healthy condition, while the internal shaft of wood is dry, and not liable to undergo rapid decay. The formation of a separative mass over the wood can therefore go on to completion.

[1] Bot. Zeit., 1873. Compare Haberlandt: Sitz. d. k. Akad. Wien, Band lxxii. Abth. i., 1875.

[2] Berichte der deutschen botanischen Gesellschaft, 1883, p. 119.

FIG. 118. Section through a lenticel in the periderm of Sambucus nigra: *k*, periderm; *r*, primary cortex; *v*, meristem, above which are the cells therefrom produced; *b*, liber. (Stahl.)

has lately shown that even in stems with the periderm free from lenticels, provision for exchange of gases is secured by certain intercellular spaces at or near the points where the medullary rays come to the periphery of the stem.

424. **Grafting.** If the cambium tissue of a young shoot is retained for a time in close apposition with that of a nearly related plant, union of the two parts may take place, and the wound may heal by the natural process before described. Success in this operation depends upon selection of suitable stock and scion, choice of the proper season, freshness of the cut surfaces, and, generally, exclusion of air from the wound. The methods of bringing the surfaces of the stock and scion together in this operation of grafting are innumerable, but for the present purpose may be referred to two principal types: (1) that in which the scion, wholly separated from the plant on which it grew as a branch, is placed in some sort of a cleft of the plant which is thenceforth to furnish it with nourishment; (2) that in which the scion is still retained in its connection with the parent plant, but is bent over and a freshly cut surface kept in contact with a cut surface of another plant, until the scion has fairly become attached by organic union. When this is accomplished, it is cut off from the parent plant. This type of grafting, in its many varieties, is known as "approach grafting." It takes place in nature, as shown in the following paragraph.

425. Two branches of one plant may become united when, after removal of a section of bark from each, the two denuded surfaces are kept in apposition for a time. Such unions of axial organs are not rare. Occasionally they may take place between two shoots at a point near the root, so that the trunk will ultimately consist of a single deeply grooved stem. The union may be between two plants of the same species, or even between plants of different species. The attrition of two branches which have grown against one another may suffice to wear off the bark on both down to the cambium, and then, if their exposed surfaces are held together for a while, union will follow. Such natural grafts are met with frequently at the borders of forests.

426. In the kindred operation of budding, a bud with a little of the tissue behind it is placed in a cleft in the bark of the stock, so that the cambium layer of the two may come into close contact.

427. The stem may be invaded by parasitic roots at any part, and its subsequent development seriously affected thereby. Such invasions often give rise to swellings, distortions, etc., by which

the structure of the stem becomes much disguised. In the case of parasites like Phoradendron, which live for several years, a vertical section through the stem of the host-plant shows how complete the union is between the host and parasite. The junction has been well compared to that which takes place between a scion and its stock, since the newer-formed tissues of both plants become perfectly united, and their subsequent growth goes on together.

428. The relations of the root to the stem are not complicated, except as regards the bundles at the "crown" of the root, or the point where it meets the stem. When the primary structure of dicotyledons in which the liber of the root is arranged in one way and that of the stem in another, as shown in Figs. 92 and 112, pages 111 and 137, is followed by the formation of a true cambium ring, the subsequent growth of root and stem is alike. Yearly additions are made in the root in the same way as in the stem; but owing to the unequal resistance exerted by the soil, such increments are often very irregular.

Roots may be produced at any part of a stem where adequate moisture and warmth are furnished; but they strike off chiefly at nodes, and, in the case of cuttings, also at the seat of injury where the callus is formed. Such secondary roots form on stems in much the same manner as root-branches do upon roots.

429. **Rudimentary and transformed branches** present few anatomical difficulties. In the structure of a branch tendril, or runner, it is generally easy to recognize the degree of reduction which the normal fibro-vascular system has undergone. In the case of underground stems and branches there are often puzzling anomalies, but they can mostly be explained by the following facts brought out by Costantin,[1] who has made a special study of a large number of rhizomes: 1. The epidermis, if present, is modified by becoming cutinized first on its outer walls, where it may acquire considerable thickness, and later on its lateral and internal walls. 2. The cortex increases either by enlargement of its cells or by their multiplication, the collenchyma diminishing or completely disappearing. 3. A cork-layer is sometimes produced at an early period, from different points in the epidermis, in the cortical parenchyma, in the endodermis, in the peripheral layer of the bundles, or, lastly, in the liber. This replaces to a great extent the fibrous layer which is so common in aerial, but never much developed in underground stems.

[1] Ann. des Sc. nat., sér 6, tome xvi., 1883, p. 164.

4. The cortex is developed largely at the expense of the pith. 5. There is only slight lignification of the elements. 6. There is a great accumulation of reserve materials.

430. The relations of a branch to the main axis of the stem seldom present any histological difficulties, the tissues of the former being continuous with those of the latter. When a branch breaks off close to the stem, and the portion remaining becomes buried by stem-tissues which are subsequently produced, a *knot* is formed.

431. **Stems of vascular cryptogams.**[1] The following outline indicates the principal points of difference between the stems of Phænogams and those of Ferns, Equisetaceæ, and their allies.

I. In vascular cryptogams the fibro-vascular bundles are closed and as a rule are concentric. 1. In Equisetum they are slender and are arranged in a circle. From the median line of each tooth of the "sheath" (see Gray's Manual) a fascicle descends perpendicularly through one internode and divides at the one below into two branches, which unite with the lateral ones next to them. 2. In Osmundaceæ the arrangement of the constituent parts of the central cylinder is not unlike that in certain Coniferæ. 3. Lycopodiaceæ have the bundles largely dependent upon the arrangement of the leaves, but the axial cylinder is essentially cauline. 4. Ferns proper may have (*a*) an axial cylinder, or (*b*) several concentrically curved bundles. In either case there may also be isolated and rather slender bundles. In both cases above mentioned the bundles coalesce to form a very complicated network, which apparently is not dependent for its character upon the distribution of the leaves upon the stem.

II. In vascular cryptogams the parenchyma in certain places may become largely sclerotic, forming dense and often brown masses, the constituent cells of which are sometimes considerably elongated.

III. The epidermis in Equisetaceæ is strongly silicified. The stomata in these plants are in the grooves; their development is peculiar in that from one epidermal cell four guardian cells are formed in one plane; but soon the two outer cells grow more rapidly and crowd down the two inner ones, so that the latter afterwards become distinctly below them. The epidermal cells of Ferns frequently contain chlorophyll granules.

432. **Stems of mosses.** Here no true fibro-vascular bundles are met with, but elongated cells fill their place, forming what

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[1] De Bary: Vergleichende Anatomie, p. 289 *et seq.*

has been termed a fascicle. Comparison of these threads — if such they can indeed be called — with the rudimentary fibro-vascular bundles of some water-plants suggests that the former are bundles of the simplest possible kind.

The parenchyma cells are bounded in true mosses by smaller, thicker-walled cells, which do not contain chlorophyll.

THE LEAF.

433. It was shown in 322 that roots are formed under the superficial tissues of the stem, and have these outer layers, or derivatives from them, as coverings during at least a portion of their growth. But leaves are never thus covered by layers of stem-tissue ; hence they are termed *exogenous* productions, while the term *endogenous* is applied to the manner in which roots are formed.

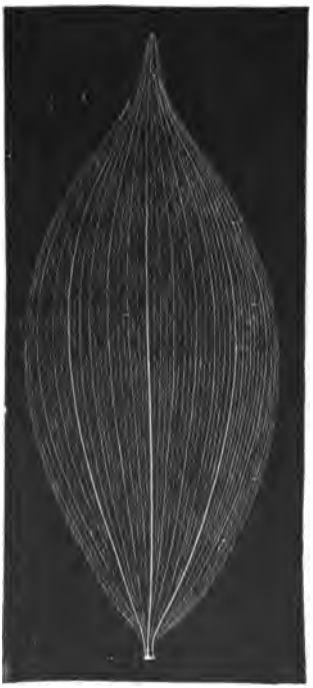
434. **Development.** In the earliest stage of its development the leaf is a mere papilla consisting of nascent cortex (periblem) and nascent epidermis (dermatogen). As soon as the papilla elongates, or becomes flattened, some of its interior cells, making up procambium tissue (see 315), differentiate into fibro-vascular bundles. But the procambium of the nascent leaf and that of the cone of soft tissue constituting the growing-point of the stem are in unbroken connection with each other; in like manner the bundles which are derived therefrom are continuous, and it is not possible to detect any line of demarcation between them. In fact, the newly formed bundles in a young leaf appear as if they are merely the slender prolongations and terminations of those in the young stem.[1]

435. With the transverse and longitudinal enlargement of the nascent leaf there is generally more or less curvature, so that the outer, lower, and earlier leaves infold the upper leaves and the growing-point of the cone. In most cases, some of the lower leaves which thus envelop the growing-point become modified to form protecting scales ; such is the ordinary structure of buds (see "Structural Botany," page 42, fig. 83).

[1] It should be remembered, however, that some of the bundles in the stem (see 365) may be derived from procambium peculiar to the stem, and which does not extend into the leaf. Hence it is necessary to distinguish between stem-bundles, common bundles, and leaf-traces. The former belong to the stem alone; the common bundles are common to stem and leaf; the leaf-traces are leaf-bundles which are in the stem and which at some point unite with other bundles of the same kind to form common bundles.

436. The growth of the young leaf is plainly terminal at first, — that is, new cells are added just in front of the older ones; but it soon becomes intercalary as well, new cells being introduced between those previously existing. According to the seat of activity, this growth may be basipetal (the zone of growth being near the base of the leaf-blade) or basifugal (the zone nearer the apex of the leaf). In most cases the base of the leaf-blade and the stipules early attain a good degree of development, after which the petiole appears.

For the purpose of noting the peculiar mode in which the leaf-blade expands, the simple device suggested by Hales[1] is perhaps as good as any. Through a piece of stiff pasteboard sharp pins are thrust, and fastened at equal distances from each other; for instance, so as to form little squares of ¼ inch side. By this simple instrument a young leaf is pierced through with holes at equal distances; then if the leaf elongates more than it widens in the space thus covered, the holes will separate in the direction of the length of the leaf more than in that of its width. The injury done to the leaf by these small perforations does not appear to check or otherwise much modify its growth.



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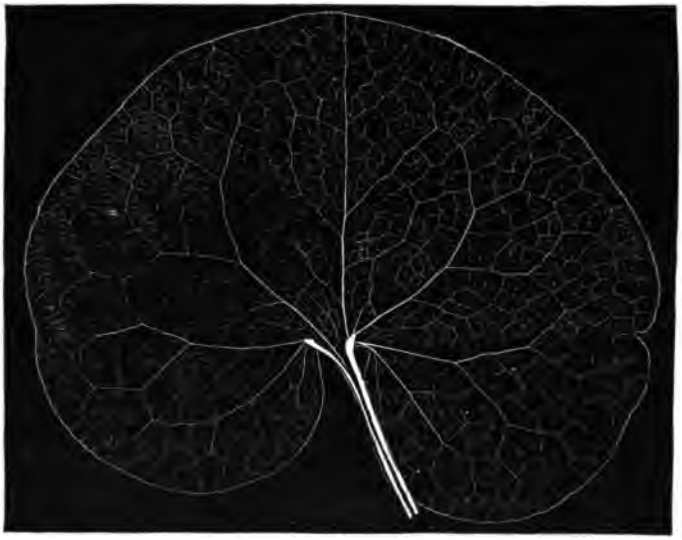
437. **Fibro-vascular bundles.** The distribution of fibro-vascular bundles in leaves has been considered in Vol. I., under "Venation." The two principal types of distribution of the bundles, there spoken of as "veins" or "nerves," were shown to be (1) parallel, (2) reticulated. *Parallel* venation (see Fig. 119) is characterized by having large "veins" or "nerves" running free through the leaf (that is, not connecting with each other), or without any obvious anastomosis; while in *reticulated* venation the veins form a more or less complicated network.

[1] Statical Essays, vol. i., 1731, p. 344.

FIG. 119. Venation of the leaf of Convallaria latifolia. (Ettingshausen.)



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438. Parallel venation is of two principal kinds: (1) that in which large nerves run in long curves from the base to the apex of the leaf; (2) that in which smaller nerves run generally at right angles from a main nerve (or *midrib*) to the edges of the leaf. In both these kinds of parallel venation the veins are more or less connected by means of inconspicuous cross-veinlets and by the anastomosing extremities, but some of the veins may be *free*.

439. Reticulated venation is likewise of two principal kinds: (1) palmate (Fig. 120), in which relatively large veins diverge from each other at the base of the leaf; (2) pinnate (Fig. 121), in which

FIG. 120. Venation of the leaf of Asarum Europæum. (Ettingshausen.)
FIG. 121. Venation of the leaf of Salix grandifolia. (Ettingshausen.)

side veins strike off through the whole length of a strong midrib. In both these cases the veins divide and subdivide and have numerous cross-connections both large and small, until the ultimate ramifications are in great part *free*.

440. Thus it appears that in both types there is abundant communication between the veins of leaves; but in some cases, especially in rudimentary and submerged leaves, in the leaves of Coniferæ, etc., the veins are very generally free, and few if any cross-veinlets are met with.

441. The fibro-vascular bundles of leaves are essentially like those of stems (see 365), and need no special description here. Their extremities are for the most part tracheïds, often arranged in double rows, but their diversities of structure and arrangement are innumerable. One of the more striking special cases of these has been already shown in the illustration of a water-pore (*v*, Fig. 55); others will be considered later (see "Insectivorous Plants"). The tracheïds which terminate the final ramifications of the veins in leaves are in close contact with parenchyma cells.

442. According to Casimir De Candolle, the leaf may be regarded histologically as a branch with its upper, that is its posterior, side atrophied.[1]

443. The stipules have the same arrangement of elements in their fibro-vascular bundles as the blade, — that is, liber below (outside), wood above (inside). But in ligules (organs which are formed by radial deduplication) the arrangement is just the reverse of this, — the liber is above, the wood below.

444. **Parenchyma.** The forms of the parenchyma cells which constitute the pulp of leaves are: (1) spherical or nearly so; (2) ellipsoidal, sometimes much elongated; (3) branched, sometimes stellate. Examples of these three are often met with in the structure of a single leaf; the upper layers generally being composed of ellipsoidal cells, the lower layers of more nearly spherical ones, intermingled with some which are branched.

445. The arrangement of the parenchyma of the leaf-blade is referred by de Bary[2] to two chief types: (1) the *centric*, in which the chlorophyll parenchyma is uniformly disposed throughout the whole organ; (2) the *bifacial*, in which there is a decided difference between the compact tissue of the upper and the spongy tissue of the lower side of the leaf.

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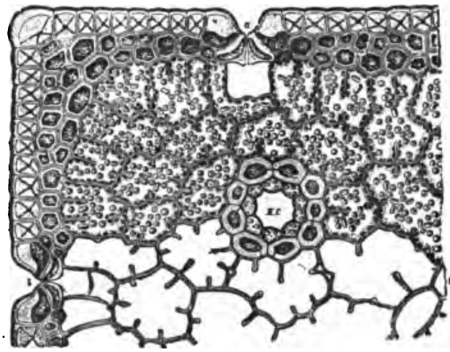
[1] Archives des sciences de la Bibliothèque universelle, 1868, tome xxxii. p. 32, "un rameau à face posterieure atrophiée."

[2] Vergleichende Anatomie, p. 423.

446. The centric arrangement has two modifications: (1) that in which the whole pulp is composed of chlorophyll parenchyma, but towards its middle plane has larger cells with less chlorophyll, and sometimes has conspicuous lacunæ (many grasses, Yucca filamentosa, Crassula, etc.); (2) that in which it is composed of layers which are uniformly distributed above and below a middle layer of colorless cells free from chlorophyll, but, in succulents, very rich in sap (Aloe, Mesembryanthemum, etc.). In both the foregoing modifications the upper layer of the parenchyma may be composed of somewhat longer cells than those below, and to them can be applied the term more generally given to those in the next type, namely, *palisade-cells*.



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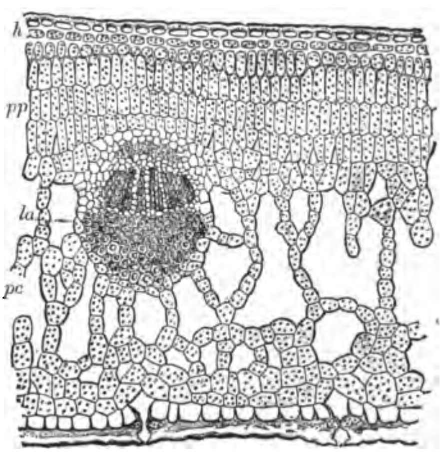

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447. The bifacial arrangement has the denser tissue in that part of the leaf which is exposed to the light. This usually consists of several layers of palisade paren-

Fig. 122. Leaf of Pinus Laricio. Cross-section of a part of the leaf, showing the stomata, hypoderma, and parenchyma. The folded walls of the parenchyma-cells (see 208) are plainly shown in the cells below the resin-passage (*HC*), where they have been emptied of their contents. (Kny.)

Fig. 123. Transverse section of a leaf of Ilex Aquifolium, showing arrangement of the parenchyma: *pp*, palisade parenchyma; *pc*, spongy parenchyma; *h*, hypoderma; *la*, fibro-vascular bundle. Stomata are found only upon the lower surface of the leaf. (Areschoug.)

chyma; but the aggregate thickness of these may not be so great as that of the spongy parenchyma on the other side of the leaf (see 205).

448. In some plants the palisade parenchyma is found almost as abundantly in the under as in the upper portions of the leaves. Bessey[1] has shown that this is the case in the leaf of the Compass plant (Silphium laciniatum): "Its chlorophyll-bearing parenchyma is almost entirely arranged as palisade tissue, so that the upper and lower portions are almost exactly identical in structure." Another plant possessing substantially the same leaf-structure is Lactuca Scariola. When its leaves are grown in the light, they take a vertical position (and generally stand north and south); but if grown in the shade, they are horizontal. The leaves which are developed in the light have palisade parenchyma on both the upper and under portions;[2] but those which are developed in the shade have ordinary parenchyma above and more or less stellate parenchyma below.

449. According to Stahl,[3] exposure of a leaf to light or shade during development has very much to do — in the plants thus far examined — with the form and arrangement of its parenchyma. The leaves of the common beech afford good material for the study of the subject. In some cases, at least, *those* which are grown in the deep shade of a grove are different in texture from those which are formed in bright sunlight.

450. The parenchyma of the petiole is generally much like that of the stem to which it is attached; layers or lines of thin-walled collenchyma sometimes extending without interruption from the stem into the petiole. In the petioles of Cycads sclerotic elements like those of the stem are often abundant, and are continuous with them.[4]

451. In some leaves which have the power of movement the petiole is much enlarged at its base, forming what is known as the pulvinus. The parenchyma of this structure is sometimes peculiar in being thick-walled on the upper side of the petiole and thin-walled on the under. Other peculiarities will be described under "Movements."

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[1] See also American Naturalist, 1877.

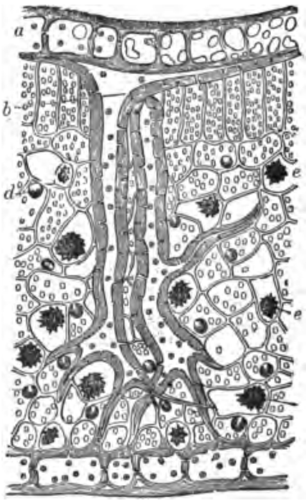
[2] Pick: Botanisches Centralblatt, 1882, vol. xi. p. 441.

[3] Stahl: Ueber den Einfluss des sonnigen oder schattigen Standortes auf die Ausbildung der Laubblätter, Jena, 1883.

Haberlandt, on the other hand, does not think the effect of light *in controlling* the character of leaf-structure is well marked.

[4] Kraus: Pringsheim's Jahrb., 1865, vol. iv. p. 305.

452. The **epidermis** of the leaf is continuous with that of the stem. Its principal features have been described in Chapter II., and only the following need now be recalled. 1. It may be simple, that is, composed of one layer of cells; or multiple,—of more than one. 2. Immediately below it may be found in some cases one or more layers of cells known as the hypoderma. 3. The epidermal cells are in unbroken contact with each other except at (1) rifts, (2) water-pores, (3) stomata. 4. Their surfaces may exhibit nearly every form of trichome.



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453. Glands secreting nectar are found on different portions of the leaves of various plants; for example, at the junction of the petiole with the blade (Poplar), at the base of the petiole (Cassia occidentalis), on the lower side of the midrib of the leaf (cotton-plant), or scattered over the lamina (turban squash). Such glands are particularly noticeable in insectivorous plants, as Sarracenia and Nepenthes (see Part II.). On making a section of one of the nectar-glands found on a young poplar leaf, the epidermis will be seen to be transformed into a double layer of thin-walled, elongated cells forming the secreting surface, which is charged, together with the parenchyma lying below it, with a syrup derived from the transformation of starch. At times the secretion from a gland is so abundant that drops of considerable size collect upon the surface of the leaf, and if rapid evaporation takes place, crystals of sugar are deposited at the gland.[1]

454. The leaves of submerged phænogams, for example those of Potamogeton and Myriophyllum, possess no true epidermis; the parenchyma is therefore in direct contact with the surround-

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[1] Trelease: Nectar and its Uses, in Report on Cotton Insects (United States Department of Agriculture, 1879), and Nectar-Glands of Populus, Botanical Gazette, vol. vi. p. 284.

FIG. 124. Transverse section through leaf of Camellia (Thea) viridis, showing: *a*, epidermis; *b*, branched liber-cell; *d*, oil-drop; *e*, crystals. (Mirbel.)

ing water. On the external surface its thin-walled cells are in close contact (there being nothing answering to stomata); but in the interior of the leaf there are often lacunæ filled with air. These were thought by Brongniart to be essentially the same as those cavities found in the parenchyma of many marsh plants.

The veins of submerged leaves have no true ducts; the elongated fascicles generally consisting merely of rows of elongated cells.[1]

455. Roots may be produced from leaves in much the same way as they are from stems; that is, some of the cells at the liber may divide in such a manner as to form a protuberance which pushes before it a part of the endodermis. As the root thus formed emerges, the tissues are speedily produced, the wood being continuous with the wood of the leaf, the liber with its liber. Roots may arise naturally in some leaves by simply placing them in contact with moist earth, or they may be produced artificially by mutilation of the petiole or lamina. Bryophyllum calycinum affords a good example of the former; Begonia, Peperomia, etc., of the latter mode of origin.

456. Buds may form spontaneously on the margin of leaves, especially those in contact with a moist surface, or they may grow from the cells under the scar where a mutilated leaf has healed.

457. In some of these cases only the epidermal cells take part in producing the meristem from which the bud is developed; in others the parenchyma just below the epidermis also divides, or the cells under the scar may produce all the axial tissue elements. Begonia is an example of the first method of production, Bryophyllum of the second, Peperomia of the third.

It is interesting to observe that in all these cases the bud forms without the intervention of the fibro-vascular bundles of the leaf. The newly formed axis has fibro-vascular bundles, which may anastomose with those pre-existent in the leaf, but usually they are entirely distinct. The axis is, however, provided with its own root-system, and after a time it becomes severed by a plane of cork from the leaf which produced it.

458. **Fall of the leaf.** In deciduous plants the leaf separates from the stem or twig by the formation of a plane of cells[2] cutting sharply through the petiole at or very near its base. The dividing plane may be partially formed early in the growing

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[1] Brongniart: Ann. des Sc. nat., tome xxi., 1830, p. 442.

[2] Called by Mohl the separative layer (Botanische Zeitung, 1860, p. 1).

season, but generally it is not far advanced in development until near the end of summer. The leaflets of the larger compound leaves — for instance, those of Ailanthus, Gymnocladus, Juglans, etc. — afford excellent material for examining the process of defoliation. Strong leaves of any of the plants mentioned are to be kept between damp (not wet) paper in a warm place for a number of hours, when the formation of the dividing plane can be observed. The plane is so far completed by the end of the second or third day that the leaflets fall with the slightest touch.

459. The strong leaves of horse-chestnut are employed by Strasburger as material for demonstrating the process of defoliation. He says that alcoholic material answers very well for the purpose, but that it happens occasionally that the distinctive brown color of the cells adjoining the cutting plane is nearly or quite lost. The petiole is to be cut through in its median line, and then several very thin longitudinal sections parallel to this are to be carefully made and placed at once in water. In a good preparation the cells making up the cutting plane should be clearly seen extending from the epidermis of the petiole to the fibro-vascular bundles. If the leaf was taken at just the right time, the preparation should show also that the cutting plane has invaded even the tissue of the fibro-vascular bundles. The plane consists of one to several layers of cells, some of which are plainly cutinized; thus, as a rule, the place of separation is a scar healed before the leaf falls.

It happens frequently that changes take place at the middle portion of the cutting plane, by which its layers near the leaf are forcibly separated from those nearer the stem; in such cases the leaf falls because it is forced off.[1]

460. The excision of the leaf usually takes place at the base of the petiole, so that the surface of the scar is even with the

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[1] "The provision for the separation being once complete, it requires little to effect it; a desiccation of one side of the leaf-stalk, by causing an effort of torsion, will readily break through the small remains of the fibro-vascular bundles; or the increased size of the coming leaf-bud will snap them; or, if these causes are not in operation, a gust of wind, a heavy shower, or even the simple weight of the lamina, will be enough to disrupt the small connections and send the suicidal member to its grave. Such is the history of the fall of the leaf. We have found that it is not an accidental occurrence, arising simply from the vicissitudes of temperature and the like, but a regular and vital process, which commences with the first formation of the organ, and is completed only when that is no longer useful" (Dr. Inman, in Henfrey's Botanical Gazette, vol. i. p. 61).

surface of the stem; but it may occur a little higher up, so that some of the petiole remains attached to the stem[1] (Rubus, Oxalis, etc.).

461. Evergreen leaves are those which remain upon the stem without much apparent change during at least one period of suspension of vegetation. The leaves of some evergreens persist through only one year, falling off as soon as those of the succeeding year have fully expanded. It is not unusual in warm temperate climates to have trees and shrubs which are normally deciduous in colder regions retain their leaves until new ones are produced.

Pines and spruces lose some of their oldest leaves every year, but new ones are as regularly formed. Their branches are never completely defoliated, but may bear at one time the leaves which have been formed during several years.

462. The colors assumed by leaves before they fall can be better examined after the subject of the pigment of chlorophyll-granules has been treated in Part II.

463. The fronds of ferns and the leaves of their allies present few peculiarities, and do not need to be here examined. The formation in ferns of the *sori*, or spore-dots, the *sporangia*, or spore-cases, and the *spores* themselves falls properly within the province of Volume III.

464. The leaves of mosses are characterized by great simplicity of structure. For their study any of the species of Polytrichum, or Hair-cap Moss, will answer. In these there is no true fibro-vascular bundle; a series of somewhat elongated and rather firm cells, known as the conducting thread, takes its place. Upon this conducting thread the parenchyma cells are distributed more or less regularly, on one side forming slender elevations four or five cells in height. The cells contain chlorophyll, and generally much starch.[2]

465. In the thallophytes there is no clear distinction of leaf and axis; the tissue consists throughout of parenchyma more or less modified. In some algæ there is often a lateral parting of the frond into segments resembling leaves; but as they are not leaves morphologically, they need no further consideration here.

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[1] For full and interesting accounts of the changes which cause the fall of the leaf, see Mohl's paper in Botan. Zeitung, 1860, p. 1, and also Van Tieghem and Guignard in Bull. Soc. bot. de France, 1882.

[2] In Strasburger's Botanische Practicum, p. 304, the student will find a full and interesting account of the structure of the leaves of Polytrichum and Mnium.

In the examination of the tissues of the organs of vegetation the student is referred to the following works: —

DE BARY. Vergleichende Anatomie (Leipzig, 1877). An octavo volume of about 660 pages, of which an excellent English translation is newly published under the title, "Comparative Anatomy of the Vegetative Organs of Phanerogams and Ferns," by A. De Bary. Translated by F. O. Bower and D. H. Scott, 1884. This exhaustive treatise gives all needful references to the literature of the subject up to 1876.

MOHL. Vermischte Schriften. This is a collection of Hugo von Mohl's most important works, which have appeared from time to time in various journals.

STRASBURGER. Das botanische Practicum (Jena, 1884). This work, of which an English translation is promised, is of very great use both to beginners and advanced students of Histology. The directions for procuring, preserving, and using material are explicit, and for the most part are conveniently arranged. The volume, of more than 600 pages, is divided into separate studies, such as the structure of the bast and wood of the pine, the anatomy of a few common leaves, etc.

OLIVER. Bibliography of the Stems of Dicotyledons (Natural History Review, 1862 and 1863). A citation of the more important works on the stems of different dicotyledons, arranged according to the natural families.

For a treatment of the anatomy of the organs of aquatics and parasites, the fully illustrated work of Chatin may be consulted.

Those curious to examine the diverse and now mostly abandoned views regarding the growth and structure of the stem, will find much of interest in the works of Du Petit Thouars and of Gaudichaud. An account of these and other views will be found in Schleiden's "Principles of Botany" (1849).

CHAPTER IV.

MINUTE STRUCTURE AND DEVELOPMENT OF THE FLOWER, FRUIT, AND SEED.

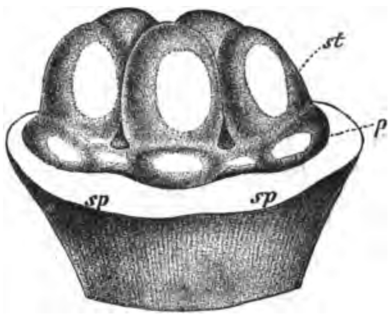
THE FLOWER.

466. In Volume I. Chapter VI., it has been shown that a flower is to be regarded as a modified branch with very short internodes and with the foliar expansions assuming forms unlike those of ordinary leaves. In the outer circle — the calyx — the parts have frequently the texture and color of foliage; but in all the other circles of the flower they are notably metamorphosed. Notwithstanding their disguises, the parts of the flower are identifiable as leafy structures arranged upon an axis. On the careful examination of flower-buds the homology between all their parts and those of a leaf-bud becomes evident. In fact, in their earliest state it is impossible to discriminate between these two kinds of buds. Each has a rounded or cone-like extremity, upon which are disposed at definite points the papillæ which are to develop into foliar organs. In one, these papillæ become green leaves; in the other, the parts of a flower.

467. Two features in the development of flowers require special attention; namely, the sequence in which the organs are produced, and the order in which the histological elements make their appearance. But it is not well in any given case to undertake the examination of the development either of the organs or of the tissues which compose them, until the student has made himself familiar with the characters of the full-grown flower.

468. Undeveloped racemes afford the best material for the study of the developing organs of the flower, and it is generally possible to find in a single young cluster flowers in all the earlier stages of development. There are two good methods of preparing the material for the compound microscope: (1) the whole raceme, first decolorized by absolute alcohol and then softened by glycerin, is to be dissected under a simple lens, and the separate flowers are to be bleached with sodic hypochlorite; or (2) the

very tip of the raceme is to be cut squarely across and placed with a drop of water under a cover-glass, when some of the youngest flowers can be seen either standing vertically or slightly inclined. The air can be drawn out from the specimen by placing the slide for a minute under the air-pump; the outlines of the floral organs will then be distinct.



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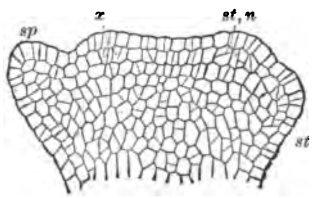
469. A still better method is to make tolerably thick vertical sections of separate flowers, one of which in each flower must be through the median line; and then, arranging the sections[1] in their proper sequence, clear them for examination either by the use of potassic hydrate (as directed in 24), or by the following method, recommended by Strasburger as applicable to many cases of thick masses of soft tissues: Treat the part first with absolute alcohol for a day or two, and then place it in concentrated carbolic acid, after which it becomes clear. For the carbolic acid either of the following may be substituted, — (1) three parts of oil of turpentine and one part of creosote, or (2) equal parts of alcohol and creosote.



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By any one of these methods it is generally possible to obtain preparations of sufficient clearness to exhibit in optical section all the internal tissues.

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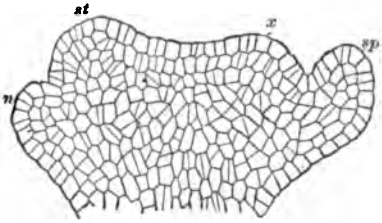
[1] Pfeffer advises that the young flowers should first be tinged with anilin blue, and then imbedded in a strong solution of gum-arabic (to which a little glycerin has been added to prevent brittleness of the mass on drying). Then, when the gum is dry, sections can be easily cut in any direction.

FIG. 125. Lysimachia quadrifolia. Flower seen from the side, and somewhat obliquely, the calyx being removed. At this period the parts of the corolla have not coalesced: *sp*, place where the excised sepals were; *p*, petal; *st*, stamen. (Pfeffer.)

FIG. 126. Lysimachia quadrifolia. Thin longitudinal section through the median line of a flower, in which the organs are beginning to form. Before the sinuses of the calyx, as well as before its lobes, cell-division has taken place on all sides; for instance, at *st*, *n*, and *x*. (Pfeffer.)

470. The fully grown flower of Lysimachia quadrifolia is thus characterized: Calyx hypogynous, deeply 5-parted, the lobes valvate or very slightly imbricated in the bud; corolla hypogynous, wheel-shaped, and deeply 5-parted with hardly any tube, its lobes convolute in the bud; no teeth between the lobes of the corolla; lobes of the corolla longer than the narrow lanceolate lobes of the calyx; stamens of unequal length, plainly united at the base, inserted opposite the lobes of the corolla, glandular; anthers barely oblong; ovary one-celled, surmounted by an undivided style and stigma, and containing 10–15 ovules on a central placenta.



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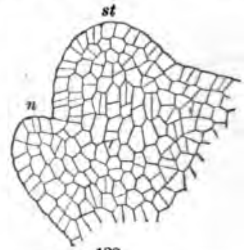

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Fig. 126 shows the appearance of a very young flower of this species; on the rounded or somewhat flattened apex of the axis minute elevations are seen, the outer being the nascent sepals. Fig. 127 shows the flower in a more advanced stage. Fig. 128 represents a portion only, the right, in a still more advanced condition. Fig. 129 exhibits all the organs of the flower, so far as they can be shown

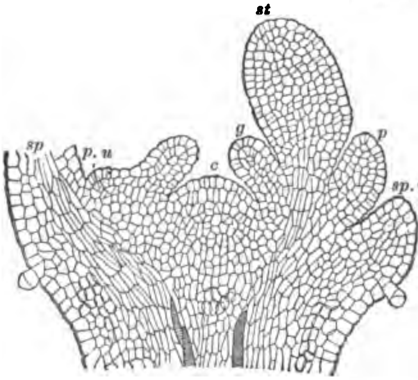

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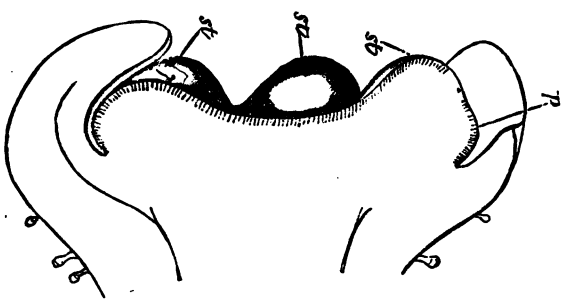
FIG. 127. Lysimachia quadrifolia. A longitudinal section through a flower somewhat more advanced than in Fig. 126; the letters are the same as in Fig. 128. (Pfeffer.)

FIG. 128. Lysimachia quadrifolia. Longitudinal section through an elevation which is considerably advanced before the appearance of the petals: *st*, stamen; *n*, cells where the petals will appear. (Pfeffer.)

FIG. 129. Lysimachia quadrifolia. A longitudinal section through a flower in which all the organs are well developed, and even the parts of the ring by which the corolla-lobes are to coalesce have begun to grow: *sp*, sepal; *p*, petal, or corolla-lobe; *st*, stamen; *g*, ovary; *c*, placenta; *sp. u*, and *p. u*, the tissue uniting the parts of the calyx and corolla respectively. (Pfeffer.)

in a single longitudinal section. Comparison of these figures gives a clear idea of the sequence in which the organs make their appearance; namely, in acropetal succession, — that is, the younger or newer are always nearest the extremity.

471. According to Payer, the sepals always precede the petals, the petals the stamens, and the stamens the pistils, in time of appearance. But in a few cases, of which Lysimachia is one, it may happen that a given circle of organs is somewhat delayed in forming; for instance, in the figures the stamens are seen as considerable protuberances before the petals are clearly outlined. This fact has been considered by some to indicate that the corolla in such cases consists of an intercalated whorl between two other whorls already somewhat developed. But a careful examination of Lysimachia and most other cases shows



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rather that the petals or the corolla-lobes are laid down in their proper sequence, but that they are temporarily outstripped by the sepals and the stamens.

The appearance of the forming flower when seen in vertical section is shown in Fig. 130, and a perspective view is given in Fig. 125, exhibiting the late-appearing petals and the much larger stamens.

472. Since the several organs of the flower are modified leaves symmetrically arranged on an axis, the histological constituents of a leafy branch will be found in the flower, albeit much modified in some of their characters. These constituents are, (1) a framework of fibro-vascular tissue, upon which is extended (2) parenchyma, covered by (3) epidermis.

Fig. 130. Lysimachia quadrifolia. Longitudinal section through a flower in which the corolla is just appearing. The elevation on the right has been cut through exactly in the median line, while that on the left has been cut on its edge. Letters the same as in Fig. 129. (Pfeffer.)

473. The **fibro-vascular bundles** of the flower are essentially the same as the collateral bundles found in ordinary green leaves, except that their elements are usually more delicate in texture, and in the inner whorls of organs very much reduced.

474. The **parenchyma** calls for no special remark beyond allusion to the fact that some one of the different kinds of internal glands is frequently associated with it.

475. The **epidermis** has stomata, — which are generally rudimentary, — and most of the forms of trichomes. One of the most interesting peculiarities of structure presented by the parts of the flower is found in the papillar outgrowths alluded to in 222. These are of course minute and short hairs, which, owing to their abundance, impart a velvety appearance to the part on which they occur. This appearance is well shown by the petals of a very large number of the flowers most common in cultivation.

476. The cuticle of the epidermal cells of the more delicate petals is sometimes very distinctly striated in an irregular manner. The walls of the cells generally have a sinuous outline.

477. The colors of petals and other colored parts of the flower are dependent either on the presence of corpuscles (the colored plastids) or of matters dissolved in the cell-sap. The following account of the coloring-matters in the very common Viola tricolor is condensed from Strasburger.

A vertical section through a petal exhibits the epidermis of the upper side as consisting of elongated papillæ, while that of the lower side has only slightly rounded ones. Just below the epidermis of the upper side there is a layer of compact cells, under which are several rows of smaller cells with conspicuous intercellular spaces. The cells of the epidermis of both sides contain violet sap and yellow granules; the layer of compact cells under the epidermis of the upper side contains only yellow granules. The striking diversities in color presented by different parts of a given petal depend wholly upon combinations of these two elements of color; namely, violet sap and yellow granules. In some places which are devoid of either of these elements there are white spots; at these places the light is refracted and reflected by the intercellular spaces which contain air. If the air is removed by pressure, the spots will become transparent.

478. The cell-sap in the parts of the flower may have almost any color, especially shades of red and blue; from this sap the coloring-matter sometimes crystallizes in the form of short and slender needles; for instance, in Delphinium Consolida.

479. **Development of the stamens.** The following outline may serve as an introduction to the study of the development of the stamens. At first, the stamen exists as a mass of homogeneous parenchyma; later, a delicate fascicle, continuous with one in the filament, becomes differentiated in one part of the stamen, the connective. Four longitudinal ridges appear on the anther, which coincide with four lines of large cells within. These cells give rise to the mother-cells of the pollen and to the very delicate pollen-sac.[1]

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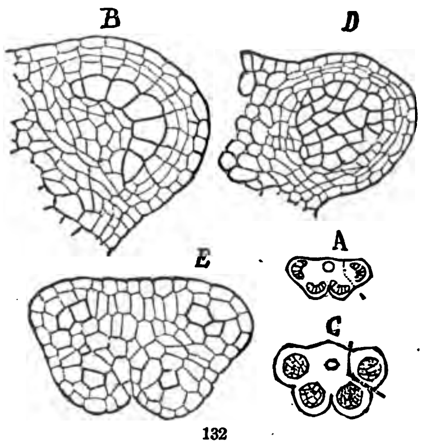
480. The mother-cells of the pollen have at first thin walls, but later these become irregularly thickened. In a large number of cases — many monocotyledons, and most if not all dicotyledons — the nucleus of a mother-cell divides into two nuclei, which themselves divide at right angles to the plane of the first division, thus producing four nuclei forming a tetrahedron. Cell-walls are next formed, and four cells are produced, which are called the *tetrad*. After the mother-cells of the pollen have been changed into tetrads, the mass of protoplasm in each of the cells of a tetrad becomes covered, as Strasburger has shown, with a new



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[1] The cells which make up the layer forming the pollen-sac are known, collectively, as the *Archesporium*. The epithelium which lines the pollen-sac has been termed the *Tapetum*.

FIG. 131. Orchis maculata. A pollen-mass in process of enlargement, with the anther-wall on the outside: *ep*, epidermis; 1, layer of cells under the epidermis remaining undivided; 2′ and 3′, layers arising from division; 3′, the endothecium. The little mass *cm*, formed by the mother-cells, is surrounded by a thickened wall. $\frac{340}{1}$. (Guignard.)

FIG. 132. *A*, transverse section of a young anther of Mentha aquatica; *B*, a fourth of this magnified; *C*, section through a young anther of Symphytum orientale; *D*, a fourth of this magnified. The dotted lines in *A* and *C* show the part taken for examination. *E*, section of a young anther of Leucanthemum vulgare (Warming.)

cell-wall, the proper cell-wall of the pollen-grains. This wall may be variously marked, sculptured, and cuticularized, giving rise to the characteristic forms and features of the grains as they are met with in the mature flower. In gymnosperms, the development of pollen-grains differs from that described in some particulars which are interesting chiefly from their resemblance to what occurs in the higher cryptogams.

481. The stigma is a surface formed of peculiar cells which secrete a viscid, saccharine matter, slightly acid in reaction. In some cases the walls of the stigmatic cells undergo the mucilaginous modification (Solanum, etc.). The wide differences which exist in the character of the cells of the stigma are illustrated by the following examples: (1) cells with no marked papillæ, as in Umbelliferæ; (2) papillose, as in Salvia, Convolvulus, Spiræa; (3) hairy, as in Hypericum, Geranium; (4) with compound hairs, as in Reseda. In some of the above the cells are rather loosely aggregated, while in others they are much more compactly combined. Below the stigma the style often has collecting hairs, as in Compositæ, Campanulaceæ, etc. (see Volume I. page 222).

482. The style is a prolongation of the ovary, and shares with it its fascicular system. In the interior there is a slender thread of loose tissue made up of thin-walled cells containing considerable food-material, starch or oil, etc. The cell-walls often pass into the mucilaginous condition. The style is sometimes tubular, and lined with the tissue just described.

483. The simple ovary is a modified leaf-blade provided with epidermis, parenchyma, and a fascicular system. The epidermis of the outside of the ovary, and that which lines its cavity, may have all the characters of ordinary epidermis; stomata and hairs may be present, the latter often being mere papillæ, which upon the ripening of the ovary into the fruit become long hairs.

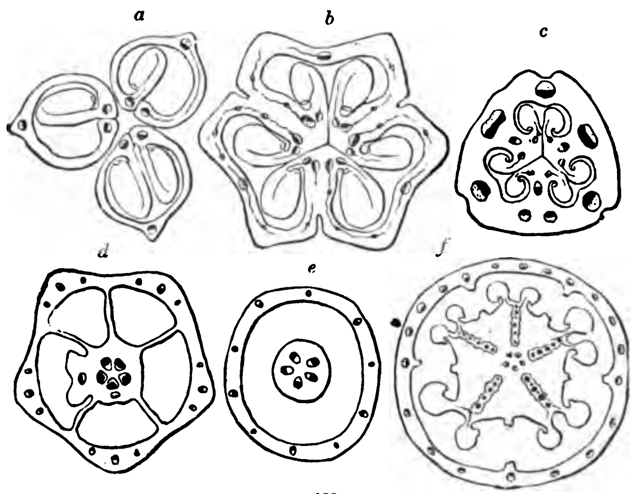
484. In the interior of the ovary there is frequently a peculiar modification, either of the epidermis itself or of the subjacent parenchyma as well. In such cases very loose tissue, sometimes appearing as if composed of felted hairs, lines the cavity of the ovary (or is found at some one portion of it). The walls of this tissue may undergo the mucilaginous modification either in whole or in part. Its cells contain a considerable amount of food-materials (oil and starch). This loose tissue, together with that of the same character found in the style, is known as conductive tissue, and serves as a path of least resistance for the penetrating pollen-tube (see Part II.).

485. The distribution of the fibro-vascular bundles in ovaries

is of much interest, and can best be examined under the two heads of "Simple Pistils" and "Compound Pistils."

486. **Simple Pistils.** The fibro-vascular bundle consists of wood and liber running through the median line of the carpellary leaf, — that is, through the dorsal suture. Two branches are given off by this bundle not far from the base of the leaf, near its two united margins, — that is, at the ventral suture.

487. The folded carpellary leaf has incurved margins; so that whatever the arrangement of the wood and liber may be in the median line of the leaf, the reverse will be found at the margins. Thus in each of the three carpels shown in Fig. 133 *a*, the fibro-



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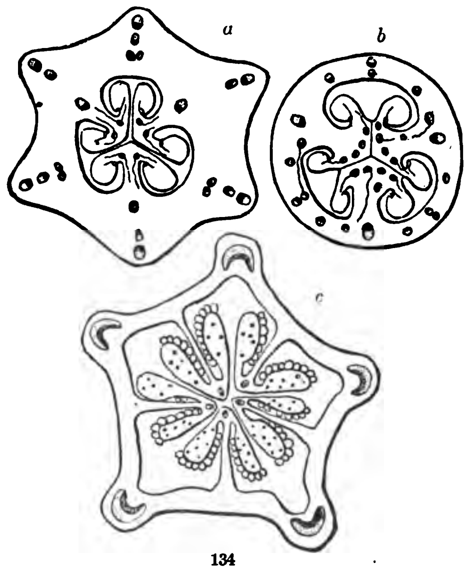
vascular bundle running through the dorsal suture has liber on its outside (the unshaded portion) and wood on its inside (the dark portion). But in each of its branches at or near the ventral suture liber occurs on the inside (that is, nearest the centre of the flower) and wood on the outside.

488. **Compound Pistils.** If several carpels unite to form a compound ovary, the same inversion of the order of the parts of the bundles (as shown in Fig. 133 *a*) will be seen when the bundles at the centre of such an ovary are compared with those at its periphery (see diagrams *b* to *f*, Fig. 133).

Fig. 133. Transverse section of superior ovaries, showing the arrangement of the fibro-vascular bundles of carpels: *a*, Eranthis hyemalis; *b*, Hyacinthus orientalis; *c*, Tulipa Gesneriana; *d*, Impatiens tricornis; *e*, Anagallis arvensis; *f*, Lychnis dioica. (Van Tieghem.)

489. But if the ovaries, instead of being superior, as those in Fig. 133, are inferior, as those in Fig. 134, further complications are caused. The fibro-vascular bundles of the several floral whorls united with the pistil are distributed in circles in the parenchyma tissue of the ovary. Thus in Fig. 134 *a*, we find five such circles, corresponding to the calyx, corolla, stamens, and dorsal and ventral sutures of the carpel. The bundles in Fig. 134 *a* are arranged in radial lines from the centre outwards; the six bundles nearest the centre of the ovary are those of the ventral sutures, and have wood outside and liber inside; in the next circle the three with reverse arrangement of elements are those of the dorsal sutures from which the bundles just spoken of branched. In Fig. 134 *b*, all the fibro-vascular bundles save those of the carpels are united to form a single circle, thus giving rise to the three circles of bundles seen in the cross-section, and at the base of the ovary even these did not exist separate. In Fig. 134 *c*, the bundles of all the floral whorls are blended for a considerable height in the ovary; finally, the bundles of the ventral sutures become separated from the rest, which continue united throughout, forming the large bundles seen on the periphery of the ovary in Fig. 134 *c*. The arrangement of the bundles in this figure should be compared with that in Fig. 133.



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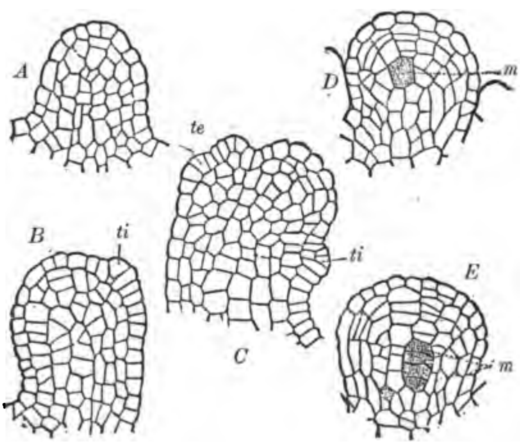
490. The structure of the peduncle and the pedicels is substantially the same as that of the stem, and the structure of

FIG. 134. Transverse section of the inferior ovary, showing the arrangement of fibro-vascular bundles both in the carpels and the external parts of the flower: *a*, Alstrœmeria versicolor, the fascicles of the whorls independent; *b*, Galanthus nivalis, the fascicles no longer so distinctly radial; *c*, Campanula Medium, the fascicles of the whorls blended. (Van Tieghem.)

the bracts is much like that of the leaf; therefore these need not be specially considered here.

491. Ovules are normally formed at definite points or lines upon the ovarian wall, which answer to the edges of the carpellary leaves. The funiculus arises as a slight elevation produced by the multiplication of a cell or a group of cells under the epidermis; in the centre of this elevation, and also under the epidermis, further development produces a spheroidal or cone-like mass, — the nucleus. Then, a little later, cells at the base of the nucleus begin to produce a cylinder (the inner integument), and shortly after, a second one is formed below and outside this (the outer integument). Subsequent development carries the outer integument quite up and around the inner one, and the nucleus; leaving a small opening (the foramen). For peculiarities in the morphology of the ovule, and for cases in which one or both integuments may be wanting, see Volume I. page 278.

492. The funiculus has a collateral fibro-vascular bundle, having its median plane coincident with that of the ovule. The



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bundle is surrounded by parenchyma and epidermis. It is frequently prolonged into the integuments, being there more or less branched.

FIG. 135. Development of the ovule of Aristolochia Clematitis. *A*, young ovule in vertical section; *B*, same, more advanced; *ti*, internal integument forming; *C*, a later stage of same; *ti*, internal integument; *te*, external integument forming; *D* and *E*, later stages of nucleus, to be described in Part II. (Warming.)

THE FRUIT.

493. The fruit is the ripened pistil. But, as shown in Volume I., "it is a loose and multifarious term, applicable alike to a matured ovary, to a cluster of such ovaries, at least when somewhat coherent, to a ripened ovary with calyx and other floral parts adnate to it, and even to a ripened inflorescence when the parts are consolidated or compacted."

494. Histologically considered, fruits present few difficulties, although the changes in form which a pistil undergoes as it ripens are not greater than the changes which it may suffer in minute structure. These histological changes are referable to a few simple kinds: (1) a great development of sclerotic elements, seen in the harder dry-fruits and in the putamen of all stone-fruits; (2) a large increase in the amount of soft-walled parenchyma, containing sap, as in the pulp of all fleshy fruits; (3) a considerable development of color, especially in the superficial parts.

495. Sections to exhibit the structure of the very hard parts of fruits are made most easily by carefully grinding the parts on a fine oil-stone. First, a fragment of the hard shell of a nut or of the putamen of a drupe is obtained by means of any strong cutting instrument, and a flat surface parallel to the plane of the section desired made by a clean file. On a glass slide a drop of Canada balsam is placed, and heated until the more volatile portion is expelled (see 111). Then the flat side of the object just prepared is held upon this balsam until the latter becomes cool and hard; and when thus securely fastened, the specimen is rubbed down on an oil-stone to any required degree of thinness. It is removable from the slide by oil of turpentine, and can afterwards be mounted in a fresh portion of balsam or of benzol-balsam (see 112).

496. The contents of the parenchyma cells of fruits depend very largely on the degree of maturity of the fruit. Changes in the contents go on from the formation of the fruit until it is fully ripe. In some of the more common cases these consist largely in the production of various sugars, especially that which is known as fruit-sugar; and organic acids, for instance, citric, tartaric, and malic acids. A consideration of these changes belongs to Part II.

497. The coloring-matters in fruits, like those in flowers, are either color-corpuscles (chromoplastids), or substances dissolved in the cell-sap. In a few cases the walls of the cells themselves have more or less color.

498. The berries of a common house-plant, Solanum Pseudocapsicum, furnish excellent material for the examination of the coloring-matters of fruits. The following account, condensed from Kraus,[1] will show the essential characters of the color-granules in this case, and it should be compared with what has been already said about the structure of chlorophyll granules and leucoplastids (168 *et seq.*), as well as with the account of the chromoplastids in the parts of flowers (477).

A section through the ripe pericarp shows that it consists of twenty to thirty or more layers of cells, in most of which color-granules occur. In the outermost cells the granules closely resemble both in form and structure ordinary granules of chlorophyll. In some of the granules the coloring-matter is evenly diffused through the whole mass, while in others it is confined to some one part, the rest of the granule remaining without color of any kind. In these cases the colored and the uncolored parts are not very sharply divided from each other.

499. Other granules less like chlorophyll-granules occur, in which there is a sharp demarcation between the colored and uncolored parts; such have been shown to be vacuolar, the vacuoles assuming widely different shapes. These are abundant in the cells which lie five to eight layers, or rather more, from the outside.

In some of these the colored portion appears spindle-form or sickle-form, in others curved twice, like the letter S. It frequently happens that several of these long granules are placed end to end, forming an irregular chain.

500. In the part of the berry which envelops the seeds the color-granules are extremely slender, and needle-shaped.[2] All of the granules lie in the protoplasm; usually in greatest number in that lining the walls, and immediately around the nucleus.

501. Occasionally in the larger pericarp-cells roundish colored objects are met with, which close examination shows are nothing but vacuoles in the protoplasm of the cell filled with colored sap; sometimes these have been mistaken for the granules themselves, but they can usually be distinguished from them without difficulty, on account of the distortion which they undergo upon slight pressure.

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[1] Kraus: Pringsheim's Jahrb., 1872, p. 131.

[2] Trécul: Ann. des Sc. nat., sér. 4, tome x, 1858, p. 154. Weiss: Sitz. d. k. Akad. Wien, 1864 (Band l.), and 1866 (Band liv.).

THE SEED.

502. The ripened ovule is the seed. In ripening, the ovule undergoes changes in the structure both of the integuments and the nucleus. The integuments of the seed answer morphologically to the primine and secundine of the ovule; the outer being the testa, or seed-shell, — also called spermoderm or episperm, — the inner the tegmen, or endopleura. The nucleus of the seed also answers to the nucleus of the ovule. The morphological relations of the different parts of the seed have been sufficiently treated in the first volume, "Structural Botany," and therefore only the histological features will now be presented.

503. Considered as a whole, the testa varies greatly in consistence; it is in some cases as dense as any sclerotic tissue, while in others it is pulpy, and in others still, membranaceous. But it is usually divisible under the microscope into two or more layers, which are not constant in their characters.

504. The ordinary layers met with in the seeds of most agricultural plants have been described by Nobbe[1] in the following terms: 1. The hard layer, composed generally of palisade or staff-like cells of considerable firmness. In Leguminosæ it is the external layer, and its exposed surface is cuticularized. In flax and species of Brassica, it is the second, in cabbage and mustard, the third layer. In a few cases the cells of this layer are tabular instead of staff-shaped. 2. The mucilaginous layer, not present in all the common agricultural seeds, is composed of cells whose walls have the power of swelling greatly when they are placed in water. This layer is sometimes found in the outer part of the testa, sometimes in the inner. 3. The pigment layer, which imparts characteristic colors to the coats of the seeds of many plants, is not constant in the form of the cells. The color may reside in the cell-wall, or in the dried contents of the cell. Sometimes a few pigment-cells are scattered among others of a neutral tint, and even among those which cannot be said to have any proper color at all. In some cases one of the other layers may contain more or less color. In a few other instances the color is not dependent on a pigment layer; for, as Frank[2] has shown, in the steel-blue seeds of species of Pæonia the color is purely a result of reflected light, and is in no wise due to the presence of any true coloring-matter. The dried seeds are dark red or dark brown; but when thoroughly moist-

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[1] Handbuch der Samenkunde, p. 73. [2] Botanische Zeitung, 1867.

ened with water (or better still in a fresh state), they are distinctly blue. 4. The protein layer, the cells of which contain granular albuminoid matters.

The layers just described are different in different seeds, and sometimes different in different parts of the same seed-coat, so that the division has really little utility.

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505. The external integument or testa may have well-developed hairs, as has been shown in Volume I. p. 306. Only one of these cases of hairs can be here described; namely, those which form the felted covering of cotton-seeds, and which are the "cotton" of commerce. These are slender cells with collapsed walls. As they approach maturity, the cells become more or less twisted; the resulting spiral is that which imparts to cotton its value as a material for spinning. Some other seeds, notably those of species of Asclepias, have long and strong hairs, but none of these have any spiral twist which fits them for textile purposes.

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Regarding the size of cotton "fibres" (hairs of the seed), the following measurements by Ordway are of interest: Maximum length in the "sea-island" variety, about two inches (five centimeters); in

FIG. 136. Cross-sections of cotton-fibres. *A A*, unmature fibres; *B B*, half-mature fibres; *C C*, fully mature fibres; *D*, section of fibre, showing laminated cell-walls. (Bowman.)

FIG. 137. *A*, Glassy, structureless fibre; *B*, thin, pellucid, immature fibre; *C*, half mature fibre, with thin cell-wall; *D* and *E*, fully mature fibre, with full twist and well-defined cell-wall. (Bowman.)

upland or "short-staple" cotton, a little over one inch and a half (three and three-fourths centimeters). The greatest width of fibre was found to be .0013 inch. A single fibre sustained without breaking a weight of 150 grains.[1]

506. It has been shown in Volume I. that the seed-coats of many Polemoniaceæ, etc., are furnished with microscopic hairs, "which come usefully into play in arresting farther dispersion at a propitious time or place. . . . The testa is coated with short hairs, which when wetted burst, or otherwise open and discharge along with mucilage one or more very attenuated long threads (spiricles) which were coiled within. These protruding in all directions, and in immense numbers, form a limbus of considerable size around the seed, and evidently must serve a useful end in fixing these small and light seeds to the soil in time of rain, or to moist ground, favorable to germination, to which they may be carried by the wind." The best example of this structure is afforded by the genus Collomia; in this the spiricles are long and very numerous.

507. The nervation of the seed-coats furnishes in many cases excellent diagnostic characters, but they need no special remark histologically. All the forms of branching of the fibro-vascular bundle of the funiculus indicate that the ovule and seed are of the nature of leaflets on the margin of the carpellary leaf.[2]

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[1] The above measurements are approximate; those which follow are the exact determinations as they are given by Professor Ordway in the Tenth Census of the United States.

Length of fibre. Maximum length found in the "sea-island" variety of South Carolina, where it was 1.996 inches. The maximum length of the upland or "short-staple" cotton was 1.669 inches. The minimum of length (0.695 inch) was found in North Carolina cotton, grown on a light, sandy loam soil.

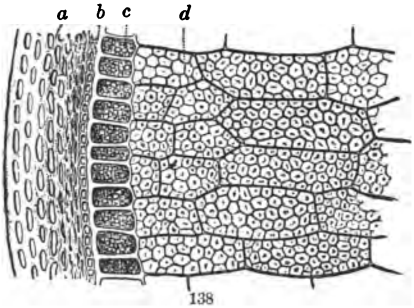
Width of fibre. The widest ($\frac{1398}{1000000}$ inch wide) was quite short (0.945 inch). By far the largest number of wide fibres come from uplands. The "sea-island" variety had a width of $\frac{878}{1000000}$ inch.

Strength of fibre. The strongest specimen examined had a breaking weight of 149.4 grains. Professor Ordway mentions some instances which lead him to think that the strength of the fibre may hold some relation to the amount of phosphoric acid in the soil where it is grown.

Weight of seeds and lint. (Maximum weight for five seeds with lint attached, 22.14 grains.) Light-weight seeds appear to come from sandy soils, heavy-weight seeds from heavy and productive soils.

[2] The reader is referred to a memoir by Le Monnier, in Ann. des Sc. nat., sér. 5, tome xvi., 1872, p. 233, and one by Van Tieghem in same Journal, 1872.

508. The so-called "grains" of the cereals are fruits instead of seeds ; the accompanying figures exhibit, therefore, not only the



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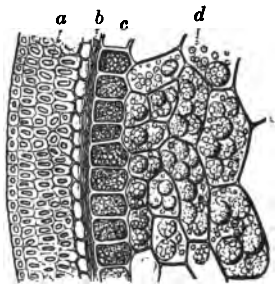

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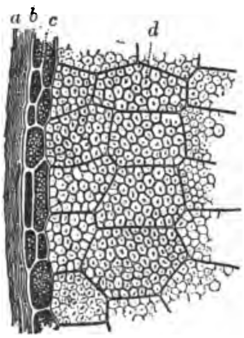
structure of the integuments of the seeds, but also of the ripened ovarian wall.

509. As shown in the "Structural Botany," page 309, the nucleus of the seed consists of the embryo and its supply of food. If the store of food is wholly within the tissues of the embryo, the



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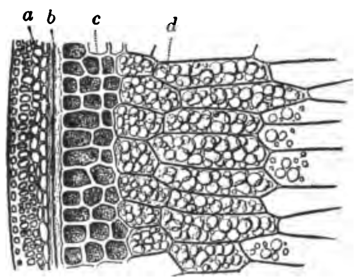

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seed is said to be exalbuminous ; if partly outside of the embryo, as, for instance, in the cereals here figured, it is said to be albuminous. The albumen is the supply of food in the nucleus of the seed which is not stored in the embryo itself.

FIG. 138. Cross-section from the periphery of the fruit of Zea Mais, highly magnified: *a*, fruit-capsule; *b*, seed-coat; *c*, adherent cellular layer; *d*, starch containing albumen of seed. (Berg and Schmidt.)

FIG. 139. A cross-section from the periphery of the fruit of Avena sativa, highly magnified: *a*, chaff; *b*, fruit-capsule with the seed-coat; *c*, adherent cellular layer; *d*, starch containing albuminoid parenchyma. (Berg and Schmidt.)

FIG. 140. Cross-section from the periphery of the fruit of Oryza sativa, highly magnified: *a*, chaff; *b*, fruit-capsule with seed-coat; *c*, adherent cellular layer; *d*, starch containing albuminoid parenchyma. (Berg and Schmidt.)

FIG. 141. Cross-section from the periphery of the fruit of Hordeum vulgare, highly magnified: *a*, chaff; *b*, fruit-capsule with the seed-coat; *c*, adherent cellular layer; *d*, starch containing albuminoid parenchyma. (Berg and Schmidt.)

510. The embryo may exist as a cluster of parenchyma cells without any clear distinction of parts, or it may possess a definitely formed axis and leaves (see "Structural Botany," p. 311).

The microscopic structure of the nucleus has been illustrated in part by the figures of the grains of cereals (see also Fig. 22, on page 47), and it has been considered also to some extent in the descriptions of the nascent root and the nascent stem in the embryo. The study of the development of the embryo within the seed belongs to a special subject, which will be treated in Part II. under "Reproduction." It therefore will suffice here to state that the parenchyma cells of which the nucleus is composed contain food materials and protein matters in large amount.

511. The proper food materials in seeds are chiefly oils and starches. The seeds of a large number of plants have been examined by Nägeli[1] with reference to the occurrence of starch, and the following facts are taken from his extensive treatise: —

Phænogams containing		Gymnosperms, Families.	Monocotyledons, Families.	Dicotyledons, Families.	Total, Families.
No starch in the seed	In all species .	3	20	190	213
	In a majority .	. . .	. . .	10	10
	In half. . . .	. . .	. . .	10	10
	In a small number	. . .	1	2	3
Starch in the albumen, not in the embryo	In all species .	1	17	16	34
	In a majority .	. . .	1	1	2
	In half. . . .	. . .	. . .	3	3
Starch in the embryo, not in the albumen	In all species .	. . .	. . .	2	2
Starch in the albuminous embryo	In all species .	. . .	4	11	15
	In a majority .	. . .	. . .	1	1
	In half. . . .	. . .	. . .	5	5
	In a small number	. . .	. . .	13	13
Starch in the embryo and albumen	In all species .	1	. . .	1	2
	In a majority .	. . .	. . .	1	1
Starch in the seed throughout	In all species .	2	21	30	53
	In a majority .	. . .	1	3	4
	In half. . . .	. . .	. . .	8	8
	In a small number	. . .	. . .	13	13

512. The protein granules in seeds are classified by Vines[2] as follows: —

[1] Die Stärkekörner, 1858, p. 387.

[2] Proceedings of the Royal Society, vols. xxviii., xxx., and xxxi. On page 62 of the volume last mentioned the following table of seeds and their aleurone grains is given: —

I. Soluble in water: Pæonia officinalis (type), Ranunculus acris, Aconitum Napellus, Nigella damascena, Helleborus fœtidus, Amygdalus communis, Prunus cerasus, Pyrus malus, Leontodon Taraxacum, Dipsacus Fullonum, Ipomœa purpurea, Phlox Drummondi, Vitis vinifera.

II. Completely, and more or less readily, soluble in ten per cent NaCl solution.

I. Soluble in water; *e. g.*, Pæonia officinalis.

II. Completely, and more or less readily, soluble in ten per cent NaCl (sodic chloride) solution.

a. Grains without crystalloids.

(*α.*) Soluble in saturated NaCl solution after treatment with alcohol or ether; *e. g.*, Pisum sativum.

(*β.*) Soluble in saturated NaCl solution after treatment with alcohol, but not after ether; *e. g.*, Helianthus annuus.

b. Grains with crystalloids.

(*α.*) Crystalloids soluble in saturated NaCl solution after treatment with alcohol or ether; *e. g.*, Bertholletia excelsa.

(*β.*) Crystalloids soluble in saturated NaCl solution after alcohol but not after ether; *e. g.*, Ricinus communis.

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a. Grains without crystalloids.

(*α.*) Soluble in saturated NaCl solution after treatment with alcohol or ether: Lupinus hirsutus (type), Vicia Faba, Pisum sativum, Phaseolus multiflorus, Allium Cepa, Iris pumila (var. atrocœrulea), Colchicum autumnale, Berberis vulgaris, Althæa rosea, Tropæolum majus, Mercurialis annua, Empetrum nigrum, Primula officinalis.

(*β.*) Soluble in saturated NaCl solution after alcohol, but not after ether: Helianthus annuus (type), Platycodon (Wahlenbergia) grandiflora, Sabal Adansoni, Delphinium cardiopetalum, Trollius Europæus, Actea spicata, Caltha palustris, Aquilegia vulgaris, Dianthus Caryophyllus, Brassica rapa, Lepidium sativum, Medicago sativa, Larix europæa, Cynoglossum officinale, Spinacia oleracea.

b. Grains with crystalloids.

(*α.*) Crystalloids soluble in saturated NaCl solution after treatment with alcohol or ether: Bertholletia excelsa (type), Adonis autumnalis, Æthusa Cynapium, Digitalis purpurea, Cucurbita Pepo.

(*β.*) Crystalloids soluble in saturated NaCl solution after alcohol, but not after ether: Ricinus communis (type), Datura Stramonium, Atropa Belladonna, Elaïs Guineensis, Salvia officinalis, Taxus baccata, Pinus Pinea, Cannabis sativa, Linum usitatissimum, Viola elatior, Ruta graveolens, Juglans regia.

III. Partially soluble in ten per cent NaCl solution.

a. Entirely soluble in one per cent sodic carbonate solution: Pulmonaria mollis, Omphalodes longiflora, Borago caucasica, Myosotis palustris, Clarkia pulchella.

b. Entirely soluble in dilute potassic hydrate.

(*α.*) Grains without crystalloids: Anchusa officinalis, Lithospermum officinale, Echium vulgare, Heliotropium Peruvianum, Lythrum Salicaria.

(*β.*) Grains without crystalloids: Cupressus Lawsoniana, Juniperus communis, Euphorbia Lathyris.

III. Partially soluble in ten per cent sodic chloride solution.
 a. Entirely soluble in one per cent sodic carbonate solution; *e. g.*, Clarkia pulchella.
 b. Entirely soluble in dilute potassic hydrate.
 (*α*.) Grains without crystalloids; *e. g.*, Lythrum Salicaria.
 (*β*.) Grains with crystalloids; *e. g.*, Juniperus communis.

513. The appendages of the seed known as the strophiole (at the base of the seed), the caruncle (at the micropyle or orifice), and the membranaceous and pulpy forms of arillus (see Volume I. pages 308, 309) do not call for further remark.

The separation of the fruit at maturity, and the separation of the ripened seed as well, are due to changes analogous to those described in 458, under the "Fall of the Leaf." Some of the special forms of mechanisms by which the detachment occurs may be examined in Part II., under "Dissemination."

CHAPTER V.

PHYSIOLOGICAL CLASSIFICATION OF TISSUES.

DIVISION OF LABOR IN THE PLANT.

514. THE simplest plant, a green cell living in water, possesses all the appliances needful for the work of vegetation; namely, a protoplasmic body containing chlorophyll, and a cell-wall protecting it. It finds in the water in which it floats, and in the sunlight to which it is exposed, everything requisite for its full activity.

515. Its work is twofold: First, that which it does not share with the animal, and which may therefore be called the proper office of the plant, — the production of organic matter out of inorganic materials, under the agency of light. This work is dependent upon the presence of chlorophyll in the cell, and is known as Assimilation. Second, that which the animal likewise can perform, — the conversion into various forms of activity of the energy stored up in food. This takes place in the protoplasm, whether chlorophyll be present or absent.

516. In a spherical cell isolated from others and leading an independent existence, floating free in the water, and therefore presenting no one part exclusively to the light, there is very slight if indeed any division of labor. One part of its cellulose, protoplasm, or chlorophyll has the same work to perform and is substantially under the same conditions as any other part. But if the cell becomes one of many aggregated to form a mass of tissue, its relations to its surroundings are not the same as before, for its exterior is no longer equally exposed either to water or to light. The cells in the interior of such a mass must derive their supply of material from without through the agency of the neighboring cells; hence division of labor begins. Inspection of the mass shows that some of its cells have the office of absorption, others that of assimilation, others that of treasuring up the products of manufacture, etc. With this incipient division of labor there are also notable changes in the form of cells, by which a more complete adaptation to a particular kind of

work is secured. These adaptations are as marked in the internal anatomy as in the external configuration.

517. The parts of a living being which have definite kinds of work to do are known as organs[1] (cf. ἔργον, work). Since they

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[1] The organs of the higher plants are reducible to three members; that is, three types of structure, which bear to each other definite relations of position and sequence of appearance. These members are the root, stem, and leaf, — to which some add also the plant-hair. In Sachs's Vorlesungen, the number of members is given as two; namely, root and shoot.

In their very youngest state all the modified leaves upon a given plant are indistinguishable from each other; the leaves which are to become petals, stamens, leaf-traps, or tendrils, are like those which are to be ordinary foliage. The same is true of modified stems and modified roots; however diverse in shape and function the modified stems or branches of a plant may finally be, they are at their very beginning precisely alike.

In the determination of the rank of an organ, that is, its reference to one of the three plant-members already enumerated, the following criteria are employed: (1) its position with respect to other parts; (2) its nascent condition; (3) its presence or absence in organisms obviously allied to the one in which it occurs, its rank in these not being obscure.

So far as the organs seen by the naked eye are concerned, it is seldom that any serious difficulty exists in the application of at least one of these criteria to the determination of their rank, and it is generally possible to use more than one. But it is different in the case of the histological organs, for (1) the position can be made out only in sections of the given part; (2) their early nascent condition is the simple cell, common to all tissues; (3) it is not easy to determine whether an organ exists in a rudimentary form in allied organisms or is wholly absent from them.

It is so difficult to apply these criteria to the study of tissues, and the results obtained are so contradictory, that there is no complete agreement among botanists as to what constitutes a histological member except the simple cell itself. In fact, as stated in 191, it is doubtful whether with the material now at hand it would be possible to construct a satisfactory system of tissue elements or histological organs upon a purely morphological basis. Even in the systems which most nearly approach this there are some physiological notions which have affected a few of the minor divisions.

A classification of tissues upon the basis of physiology alone is open to serious objections; one kind of work in the plant can be performed by diverse tissues, and on the other hand one kind of tissue can perform more than one kind of work. This is illustrated by the structural elements through which mechanical ends are reached; the long bast-fibres, woody fibres, collenchyma, and short sclerotic parenchyma, — very diverse elements, but accomplishing the same result. Yet one of these, namely, the woody fibres, is among the most important of the elements by which crude liquids are carried through the plant.

Moreover, in the examination of the minute structure of a part it is not easy to discriminate between the different offices which one of its given elements may fill, because the element is associated with so many others in the formation of a complex organ.

are parts of a whole, — the organism, — they must have definite relations to each other as regards position and office.

518. The relations of origin and position, so far as the organs of the plant are concerned, are discussed in the first volume; the relations of origin and position of the component parts of their structure have occupied the earlier portion of the present volume. From a review of the facts there presented, it appears that any given part may subserve different ends; for instance, a leaf may carry on its proper work, namely, that of assimilation, and at the same time may aid as a tendril, and, in the case of Nepenthes, as a stomach for digestion. On the other hand, it is equally clear that the same kind of work may frequently be performed by different parts. For instance, the proper work of the leaf can be carried on by any green tissue; not merely in proper leaves, but in the cortex of young stems, and even in the outer tissues of young roots of certain aerial plants. It is therefore sometimes advantageous in Vegetable Physiology to distinguish between systems of tissues having different offices, rather than between organs which are often masses of heterogeneous tissues.

519. Among the systems of classifications of tissues chiefly upon a physiological basis is that of Haberlandt, which is as follows: —

A. The Protective System.
  1. Of the surface (Epidermis, cork, and bark).
  2. Of the skeleton (Bast-fibres, libriform cells, collenchyma, and sclerotic parenchyma).

B. The Nutritive System.
  1. Absorbing system (Epithelium of roots and the root-hairs; absorbing tissue of haustoria, etc.).
  2. Assimilating system (Chlorophyll parenchyma, both palisade and spongy).
  3. Conducting system (Conducting parenchyma, vascular bundles, latex cells and tubes).
  4. Storing system (Reserve-tissues of seeds, bulbs, and tubers; water-tissue, etc.).
  5. Aerating system (Aeriferous intercellular spaces, together with their external openings, stomata and lenticels).
  6. Receptacles for secretions and excretions (Glands, oil, resin, and mucus canals, crystal-sacs, etc.).

To these might be added the groups of tissues concerned in reproduction.

MECHANICS OF TISSUES.

520. In Haberlandt's classification[1] the tissues having a mechanical office to fill are brought into one group, which is then subdivided into (1) those tissues which protect the softer tissues of the interior from the harm which would result from exposure, and (2) those which hold the soft tissues in place. An examination of the work performed by tissues may accompany an investigation of the work by organs themselves; in the examination of the work of organs in Part II. the necessary facts relative to their structure will be presented.

521. Those tissues which serve simply to impart strength to the plant belong almost as much to lifeless as to living parts, and can best be examined before the subjects of physiology are taken up. The present division has for its object the consideration of that which in Haberlandt's classification is called the skeleton, and which is known to serve chiefly mechanical ends.

522. In the case of a water-plant, for instance an alga, which has about the same specific gravity as the water in which it is borne, no special mechanical support is demanded. Its own buoyancy suffices to keep the structure as a whole in place; while the different parts of the simple organism have a degree of stability which enables them to resist the action of the waves. As might be expected, such an organism can attain a very great size; for instance, Macrocystis pyrifera of the Southern Pacific Ocean has been known to measure nearly one thousand feet, and less trustworthy measurements have been recorded which far exceed this. In this and other water-plants the medium which buoys the plant up takes the place practically of any internal framework.

523. A land-plant, existing in a far lighter medium than the water-plant, must have a definite mechanical support. Those species of Calamus which furnish the "rattan" of commerce possess a terminal shoot from which are unfolded in rapid succession strong leaves armed with recurved hooks. Having reached the thickly clustering tops of a tropical forest, the terminal bud develops its leaves, and these cling with tenacity to the branches upon which they rest, so that the mechanical support is afforded in this case by the vegetation beneath. Thus supported, the extension of the shoot is indefinite, so that examples of Calamus

[1] Physiologische Pflanzenanatomie (Leipzig, 1884).

with a length of 300 feet are not uncommon, and some figures much higher than this are noted.

524. In both the above cases the extraordinary size has been attained with very little expenditure of material for mere mechanical support. The same is true, although in a less striking because a more familiar manner, in our ordinary twining and climbing plants; other plants or outside supports of some kind being necessary to bring their stems and leaves into the best relations to their surroundings. But what tissues serve to keep erect or in position the larger plants which are not water-plants or climbers? What tissues serve mainly mechanical ends?

525. The subject was extensively investigated, so far as monocotyledonous plants are concerned, by Schwendener,[1] in 1874, since which time some important additions have been made. According to Schwendener, the mechanical elements in the plant are (1) bast-fibres, (2) libriform cells and fibres, (3) collenchyma cells. That these are the chief elements of strength, especially in monocotyledonous plants, appears from his instructive experiments, which have been repeated by others. Strips, 150 to 400 mm. in length and about 2 to 5 mm. wide, were carefully taken from stems or leaves and immediately fastened in a vise at one end, the other end being firmly grasped by strong pincers to which weights could be attached at will. Behind a strip, vertically suspended from the vise, a measuring-bar was placed, so that any elongation of the strip under tension could be accurately measured. After the apparatus was properly adjusted, a small weight was attached to the pincers, the elongation of the strip observed, and the weight then removed in order to see whether the strip recovered its original length. Up to a certain point the recovery was found to be complete; beyond this point the elasticity was lost, and not again regained.

526. Strips from the middle part of the leaf of Phormium tenax, 390 mm. long and 1.5 to 2 mm. wide, were placed in the apparatus and subjected to the action of a weight of 10 kilograms. They became 5 mm. longer, but on removal of the weight were found to recover their original length; in other words, they remained perfectly elastic under this weight. A weight of 15 kilograms broke the strips into two parts. These strips contained only five fibro-vascular bundles, with an amount of bast which was believed to be about half a square millimeter in cross-

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[1] Das mechanische Princip im anatomischen Bau der Monocotylen (Leipzig, 1874).

section. From this experiment Schwendener places the strength of the bast of Phormium tenax at 20 kilograms per square millimeter.[1]

527. The tables in the notes show that good bast equals good iron in its tensile strength within the limits of elasticity, while in its breaking-weight it is greatly exceeded by the latter. Schwendener well remarks that Nature has given her whole care to providing that these mechanical elements should be strong within the limits of elasticity, and with good reason; for beyond those limits the plant gains nothing by greater strength. Attention is called also to the great difference between bast and the metals with regard to their elongation under weight.

[1] The results of experiments made with the bast of various plants in the manner described are given below. Most of the cases cited are from Schwendener; others are from Haberlandt (Physiologische Pflanzenanatomie, p. 105). The determinations for metals are from Weisbach.

Name.	Elongation in 1000 parts.	Tensile strength in kilograms per sq. mm. (within limits of elasticity).	Breaking-weight in kilograms per sq. mm.
Phormium tenax	13.	20.	25.
" "	14.	16.	
Fritillaria imperialis	12.	. . . .	
Lilium auratum	7.6	19.	
Jubæa spectabilis	12.6	20.	
Dasylirion longifolium	13.3	17.8	21.6
Dracæna indivisa	17.	17.	21.8
Hyacinthus orientalis	. . . .	12.3	16.3
Allium Porrum	. . . .	14.7	17.6
Polytrichum juniperinum (stem) . .	. . . .	. . . .	7.5
" " (seta) . .	. . . .	. . . .	11.5
Papyrus antiquorum	15.2	20.	
Molinia cœrulea	11.	22.	
Pincenectia recurvata	14.5	25.	
Dianthus capitatus	7.5	14.3	
Secale cereale	4.4	15 to 20	

These should be compared with the results of determinations made with other materials: —

Name.	Elongation in 1000 parts.	Tensile strength per sq. mm.	Breaking-weight in kilograms.
Malleable iron in rods	.67	13.13	40.9
" " in wire	1.00	21.9	
" " in plate	.80	14.6	
Hammered German steel . . .	1.20	24.6	82.
Brass	.75	4.85	
Brass wire	1.35	13.3	
Cast zinc	.24	2.3	
Copper wire	1.00	12.1	
Silver	. . .	11.	29.

528. The strength of other tissues besides bast has been measured; thus Ambronn assigns to collenchyma a breaking-weight of 12 kilograms per square millimeter, and these cells become permanently elongated under a weight of from 1.5 to 2 kilograms.

Haberlandt found that the breaking-weight of the internal "thread" of the common graybeard lichen, Usnea barbata, is 1.7 kilograms per square millimeter, but that this thread could be stretched to double its length before breaking. The breaking-weight of cotton fibre is calculated to be between 18 and 20 kilograms per square millimeter, and that of the seed-hair of Asclepias Syriaca not far from 40 kilograms.

529. Examination of any of the figures of fibro-vascular bundles given in Part I. shows how well their elements are distributed in order to secure the greatest strength with economy of material. To the elements which impart strength to a bundle Schwendener has given the name *stereom;* to the other parts of the bundle, *mestom;* thus the fibres are stereom elements, the ducts are mestom elements.

530. The striking adaptations[1] of the fibro-vascular bundles to serve as light and very strong building materials in the plant

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[1] The following table from Schwendener, with a few illustrative examples, is given to serve as a guide to the student in tracing out a few of these adaptations: —

DISTRIBUTION OF MECHANICAL ELEMENTS IN MONOCOTYLEDONS.

I. In cylindrical organs.

1. System of subepidermal nerves of bast. Simple fascicles of bast lie under the epidermis.
   First type. Arum, Arisæma.
   Second type. Petioles of Colocasia and Alocasia.
2. System of compound peripheral girders. Subepidermal fascicles of bast unite with those which lie more deeply to form girders in which the "web" or binding-tissue is partly mestom, partly parenchyma.
   Third type. Stems of Scirpus cæspitosus and Eriophorum alpinum.
   Fourth type. Stems (above ground) of Cyperus alternifolius.
   Fifth type. Stems of Schœnus nigricans.
   Sixth type. Stems of Juncus effusus.
   Seventh type. Carex lupulina.
   Eighth type. Scirpus lacustris.
   Ninth type. Isolepis pauciflora.
   Tenth type. Cladium Mariscus.
3. System characterized by a nerved hollow cylinder, the nerves of which are united with those at the epidermis.
   Eleventh type. Many grasses; *e. g.*, Alopecurus pratensis.
   Twelfth type. Panicum Crus-galli.
4. System of peripheral bast-fascicles strengthened by mestom.
   Thirteenth type. Zea Mais.

are seen plainly when the distribution of the bundles in the stems of monocotyledons is examined in cross-section. In many cases the shape of the section of the bundle is nearly that of the well-known "I" or "H" beam or girder. In the most clearly marked instances the stereom portion is well developed on both sides of the mestom, and thus forms the "flanges" or "plates," while the mestom is the "web;" the stereom has therefore to bear either compression or tension, according to the bending of the part. It will further be observed that in all cases the beam is placed with respect to the rest of the stem, so as to insure the greatest efficiency of the stereom portion.

But it is only upon a careful examination of the many methods of arrangement of the stereom and mestom in the bundles of diverse forms of dicotyledonous stems, together with an examination of the arrangement of the bundles themselves with respect to the surrounding tissues, that the adaptations of the various elements to strength can be fully appreciated.

The modes of distribution of the stereom and mestom met with in monocotyledons are so numerous that they cannot be reduced to a few types; their diversity is so great that they can only with difficulty be brought into any system of classification.

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5. System of subcortical fibro-vascular bundles with strongly marked bast development.
   Fourteenth type. Bambusa species.
   Fifteenth type. Palms.
   Sixteenth type. Yucca.
   Seventeenth type. Musa.
   Eighteenth type. Maranta.
6. System of subcortical fibro-vascular bundles united tangentially.
   Nineteenth type. Juncus Gerardi.
7. System characterized by a simple hollow cylinder with imbedded or attached fascicles of Mestom.
   Twentieth type. Commelynaceæ.

II. In bilateral organs.
1. System of subepidermal girders.
   First type. Leaves of Cyperus.
   Second type. Middle part of leaves of Zea.
   Third type. Leaves of Musa.
   Fourth type. Leaves of Tradescantia.
   Fifth type. Leaves of Pardanthus.
2. System of internal girders.
   Sixth type. Leaves of Cypripedium.
   Seventh type. Petiole of Aspidistra.
3. System of complex girders: subepidermal nerves of bast combined with interior girders.
   Eighth type. Petioles of many palms.

531. The distribution of material in the skeleton of a ligneous dicotyledonous plant is somewhat different from that in a monocotylèdon.[1] More of the mechanical work falls on the proper wood, but even here in some cases the bast serves an important purpose.

532. The data for calculating the strength of the woody stem and branches of a dicotyledonous plant are to be found in various works on mechanical engineering; but it is to be borne in mind that the figures given for timber are usually based on experiments with dry heart-wood.

533. The trunk is to be regarded as a column bearing the weight of the whole crown of branches, each of these being a tapering beam supported at one extremity. The crushing-weight the crown exerts upon this column is far within the limits of safety, even when the liability of the trunk to be much bent and twisted by high winds is taken into account. The branches at their point of union with the trunk form different angles in different plants,[2] and this angle must be taken into consideration

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[1] DISTRIBUTION OF MECHANICAL ELEMENTS IN DICOTYLEDONS.

1. With bast in the bark.
   First group. Axial organs when young have an unbroken ring of bast; in much older stems this is interrupted or cast off. Aristolochia.
   Second group. Axial organs with a layer of bast-bundles which is thrown off later. The bast-bundles form the first mechanical system, which is soon replaced by the ring of wood. Nerium Oleander.
   Third group. With simple ring of bast-bundles in first year, later with isolated bast-fibres. Æsculus Hippocastanum.
   Fourth group. With strong bast, even when far advanced. Tilia.
   Fifth group. With subepidermal bast-nerves. Russelia.
2. With transition to an intra-cambium ring of libriform cells.
   Sixth group. The cambium of the bundles lies partly outside, partly inside the mechanical ring, or is imbedded therein. Gaillardia.
   Seventh group. Isolated vascular bundles. Silphium perfoliatum.
3. Intra-cambium libriform ring without medullary rays.
   Eighth group. Without bast on the outer side of the cambium or cambiform layer. Impatiens Nolitangere.
   Ninth group. With larger or smaller amounts of bast on the outer side of the cambriform. Urtica dioica.
   Tenth group. In the libriform elements all shades of transitions to ducts. Mirabilis Jalapa.
4. Intra-cambium libriform ring with parenchyma rays.
   Eleventh group. Rays formed of elongated cells. Vinca major.
   Twelfth group. Typical dicotyledons with medullary rays.

[2] McCosh has given the angles in a large number of plants, a few of which are here cited: Ash, 60°; horse-chestnut, 50° - 55°; alder, 50°; elm, 50°; oak, large branches, 50°, small branches, 65° - 70°; beech, 45°; linden, 40°. He calls attention to the fact that in these and many other cases the angle at which the